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BULLETIN

OF THE

NATIONAL RESEARCH COUNCIL

Vol. 1, Part 1 OCTOBER, 1919 Number 1

THE NATIONAL IMPORTANCE OF SCIENTIFIC AND INDUSTRIAL RESEARCH

THE PURPOSE OF THE NATIONAL RESEARCH COUNCIL

BY GEORGE ELLERY HALE

HONORARY CHAIRMAN

When a violent revolution occurs amongst a highly civilized people, it can not fail to give a sudden impulse to their feelings and ideas. This is more particularly true of democratic revolutions, which stir up at once all classes of the people, and at the same time beget high ambitions in the breast of every citizen. The French made surprising advances in the exact sciences at the very time when they were completing the destruction of the remains of their former feudal society; yet this sudden fecundity is not to be attributed to democracy, but to the unexampled revolution which attended its growth.—*de Tocqueville, Democracy in America.*

The most brilliant period in the history of science in France followed close on the heels of the Revolution. In the stirring days of the First Empire, the Paris Academy of Sciences comprised in its membership the strongest group of investigators ever assembled. The intellectual life of the nation had been quickened to its depths, and in spite of the devastation of the Terror, which included Lavoisier among the victims of the guillotine, science attained a prestige far higher than it had ever known during the tranquil days of the old régime. The nation instinctively turned to the Academy for advice and assistance in the initiation of many new enterprises, and ministers, parliaments, administrators and state assemblies often sought its aid and accepted its decisions. The leaders of the Revolution, and subsequently Napoleon himself, reëstablished the old Academy on firmer foundations, and accorded it privileges never experienced under the monarchy. The distinguished company of scientific investigators included in the expedi-

tion to Egypt proved that Bonaparte, who was soon to attain supreme power, fully recognized the value of science to the state.

The establishment of our own National Academy of Sciences during the Civil War, and its activities in the study of military and industrial problems for the Government, affords another illustration of the effect of war in promoting scientific research. The chief events of this period have been sketched in an address before the National Engineering Societies, and need not be repeated here.[1] Nor is this the place to enter into a discussion of the relationship between science and war. Suffice it to say that de Tocqueville's statement quoted above probably applies, not merely to revolutions, but also to such wars as that of the present day. The intellectual stimulus accompanying great upheavals, however they originate, finds expression in unusual achievements in science.

At the present moment we are confronted by a fact which requires no general demonstration to bring it into view: throughout the civilized world the national importance of science and research is appreciated as never before. Even if there had been no intellectual stimulus, the present great war would have forced science to the front. In the first days of the conflict, the nations of the Entente were faced by problems soluble only through the aid of scientific research. Statesmen whose exclusively classical training had afforded them little or no means of appreciating the significance of science were compelled to summon investigators to their aid in order to overcome difficulties demanding instant solution. The question of manufacture, serious as it was, frequently held second place to the necessity for research. Thus in England it was evidently impossible for the glass factories to produce the special kinds of optical glass needed for periscopes, gunsights, field glasses, and many other military instruments, until the methods of making these glasses, previously worked out in Germany, had been rediscovered by British investigators. So with scores of other problems forced upon the nation under the stress of war. Scientific research was the first requisite, and both men and funds must be provided without delay.

No intelligent statesman, however, could meet such a situation without appreciating its obvious implications. Successful research demands trained investigators, and these cannot be produced in a day. It also demands adequate provision of funds, not merely during the feverish moments of war, but throughout those long periods of calm, when the foundations that underlie the success or failure of a nation are laid. The British people, in spite of wholly inadequate appreciation of science by former leaders of their government, have never failed to produce

investigators of the highest type. Men like Newton, Darwin, Faraday, and Kelvin have appeared in unbroken sequence from the earliest times, and fortunately there are no present indications that this splendid succession will be broken. The great Cambridge school of mathematical physics, powerfully supplemented during nearly half a century by the Cavendish Laboratory, has been a foremost agency in the development of men qualified for research. But the means at the disposal of the universities have been sadly limited, and the government has persistently refused to recognize that no public funds are more productive than those that are devoted to advancing knowledge.

The recent appropriation of one million pounds by the British Government for the promotion of scientific and industrial research, and the large sums provided for the same object by the Governments of Canada, Australia, and other British colonies; the establishment of a great national laboratory of chemistry and physics in Japan; and the similar undertakings already initiated in France and Italy, and projected in Belgium, are significant signs of the times. It is plain that we in the United States must not fail to profit by an opportunity which other nations have already seen and grasped. Fortunately the way has long since been prepared, and the initial steps have been taken in a truly national movement for the advancement of science and research.

The National Academy of Sciences was established by Act of Congress, signed by President Lincoln on March 3, 1863. Its charter states that "the Academy shall, whenever called upon by any department of the Government, investigate, examine, experiment, and report upon any subject of science or art." Under this provision, the Academy dealt with many military problems during the Civil War, and since that time it has frequently been asked by the President, by Congress, and by heads of Government Departments to report on scientific and technical questions. In April, 1916, when the unwarranted attack on the *Sussex* had brought our relations with Germany close to the breaking point, the Academy offered its services to the President. He at once requested that steps be taken to organize the research agencies of the country, not solely with respect to the necessities of possible war, but also because of the importance of developing and utilizing them more effectively under peace conditions. This led to the establishment in September, 1916, of the National Research Council, a federation of governmental, educational, privately endowed, and industrial research agencies, resting upon the charter of the National Academy, and extending the scope of its activities into every branch of the mathematical, physical, and biological

sciences, and their applications to engineering, medicine, agriculture, and other useful arts.

Thus our National Research Council differs fundamentally in several respects from the Advisory Councils for Scientific and Industrial Research recently established by the British, Australian, and Canadian Governments, though its general objects are similar to theirs. Those Councils are branches of the Government, with officers appointed by the party in power and thus subject to political influences and exigencies. The National Research Council is closely connected with the Government, through the charter of the Academy and the Executive Order issued by President Wilson on May 11, 1918, which provides for the coöperation of Government Departments, and for the appointment by the President of representatives of their scientific and technical bureaus to membership in the Research Council on the nomination of the National Academy of Sciences. The constitution of the Research Council is determined, however, by the National Academy, and this assures its scientific soundness. Moreover, the scheme of organization adopted by the Academy provides that the several divisions of the Research Council shall be made up of nominees of leading national scientific and technical societies interested in research. This gives the Council a thoroughly representative character, and makes it an actual federation of research agencies. Thus it is peculiarly well fitted to secure the cordial coöperation of the numerous elements that must work in harmony, if extensive plans for coöperation in research are to be carried into effect.

Throughout the period of the war, the Research Council devoted all of its energies to the organization and conduct of research for military and industrial purposes.[2] In undertaking the larger activities rendered possible under peace conditions, the Council recognizes that one of its chief functions is to promote a wider appreciation of the national importance of scientific and industrial research. It is probably true that this task is less difficult in the United States than in any other country. The interest of the American public in scientific progress is unquestioned, and many of our great corporations have long since demonstrated their appreciation of the practical value of research. Notable illustrations, which will be fully described in *The Bulletin of the National Research Council* are afforded by the work of the great research laboratories of the American Telephone and Telegraph Company (Western Electric Company), the General Electric Company, the du Pont de Nemours Company, the Eastman Kodak Company, and the Westinghouse Company, to cite only a few outstanding examples. One

of these corporations spends as much as three million dollars annually for research, and in all cases the resulting profits are so great that their laboratories and staffs of investigators are constantly expanding.

Parallel with this fast multiplying appreciation of research by industrial leaders, we find equally striking demonstrations that in other fields the importance of science and research have been widely felt. Tyndall, speaking in New York in 1873, at the conclusion of his very successful series of popular lectures on science, recognized both the opportunity and the need of that day:

> It would be a great thing for this land of incalculable destinies to supplement its achievements in the industrial arts by those higher investigations from which our mastery over Nature and over industrial art itself has been derived.

The great popularizer of science set an excellent example by devoting the proceeds of his lecture tour to the establishment of traveling fellowships for American students. "The willingness of American citizens to throw their fortunes into the cause of public education," cited by Tyndall as even then "without a parallel in my experience", has since led to the development of large universities, in many of which faculty members devote themselves to research to the full limit of their capacity. Heavily endowed research foundations have been established, and the research functions of Government bureaus have greatly increased. Thus the way has been cleared for new advances, which the unique conditions created by the war will certainly facilitate.

Optimistic as we may reasonably feel, however, in view of the progress already attained, we are in no danger of believing that our object has been already accomplished in any large degree. Many tendencies of the time indicate both the opportunity and the necessity for further effort. Not least of these is a widespread public preference for sensational discovery, even if based on little or no evidence, rather than for solid accomplishment of more sober sort. Pseudo-scientific journals, taken by thousands of enthusiastic amateurs, often feed their readers on the veriest nonsense in the guise of science. Charlatans offering fabulous wares are successful in securing appropriations from Congress. Such indications suffice to show the importance of rendering the sound results of scientific and industrial research more widely known, in language easily understood by all intelligent readers.

Again, we see many industries conducted on purely empirical lines, without the enormous advantages that scientific method would entail. The leaders of these industries are almost invariably ready to be con-

vinced that their products could be improved and their profits increased by research, and the National Research Council is actively engaged in demonstrating the advisability of a general adoption of the research policy that has already proved so effective in many individual cases.

Finally, to mention here only one more direction in which effort must be made, we find those industries which have awakened to the importance of research, drawing from the universities and research foundations, by superior financial inducements, the men on whom we must depend for the fundamental contributions to knowledge from which industrial progress springs. Fortunately, such industrial leaders as Dr. J. J. Carty, vice-president of the American Telephone and Telegraph Company, have strongly emphasized the absolute necessity of cultivating science for the sake of advancing knowledge. It is plain that the skilled investigators needed in rapidly increasing numbers to man the laboratories of industrial research must be developed by the universities and schools of technology. But it is also clear that this draft on the supply of competent research men must not seriously deplete the ranks of those who are advancing knowledge. The universities should have ample means to support research, and the industries, especially those that profit most from science, should aid them by establishing research fellowships, professorships, and adequately endowed laboratories. Dr. Carty emphasized this view in his presidential address to the Institute of Electrical Engineers in 1916:

> By every means in our power, therefore, let us show our appreciation of pure science, and let us forward the work of the pure scientists, for they are the advance guard of civilization. They point the way which we must follow. Let us arouse the people of our country to the wonderful possibilities of scientific discovery and to the responsibility to support it which rests upon them, and I am sure they will respond generously and effectively.

The present *Bulletin* is the first of a series to be published by the National Research Council. It comprises the views of some of the members of the Advisory Committee of the Council on the national importance of scientific and industrial research. These statements are exceptionally significant, on account of the experience on which they are based. The Honorable Elihu Root, for many years Chairman of the Board of Trustees of the Carnegie Institution of Washington, has been in close touch with research in many fields. In surveying its possibilities in their broadest aspects, he has recognized the importance of securing a higher degree of organization, and much more effective coöperation among investigators than they have ever enjoyed. A super-

ficial view of the matter might suggest the conclusion that organized effort in science would hamper the individual investigator and hinder personal initiative. It is only necessary to examine coöperative researches now in progress in astronomy, geology, and other fields in order to appreciate that the effect of well planned coöperation is to stimulate the individual and to bring out his best and most original effort. The National Research Council is strongly opposed to all attempts at central control of research, but favors the initiation of coöperative undertakings, provided that they be so devised as to encourage individual initiative. Future numbers of the *Bulletin* will illustrate possibilities of this nature.

The other statements in this *Bulletin* have also been prepared by well-known men familiar, through long experience, with scientific and industrial research. In pointing out the benefits that will accrue to those industries that utilize research most freely, they base their conclusions on practical results, of which they have personal knowledge. Manufacturers who have not yet recognized research laboratories as necessary adjuncts of their business will do well to ponder their advice, and inquire into the methods and successes of industrial research. The National Research Council will do everything in its power to facilitate such inquiries, both by publication in the *Bulletin* of accounts of research laboratories of many descriptions and by its series of research exhibits, designed to illustrate in a striking and effective manner the latest discoveries and advances in science and technology. The first of these exhibits, soon to be opened, will be devoted to the wireless telephone, which will be demonstrated in working form, and illustrated as the gradual outgrowth of researches planned, for the most part, without reference to any other object than the advancement of knowledge.

[1] See Hale, War Activities of the National Research Council, *Proceedings of the American Institute of Electrical Engineers*, July, 1918.

[2] See Third Annual Report of the National Research Council, transmitted to Congress in the *Annual Report for 1918 of the National Academy of Sciences.*

THE NEED FOR ORGANIZATION IN SCIENTIFIC RESEARCH*

By Elihu Root

Chairman of the Board of Trustees, Carnegie Institution of Washington

I have no justification for expressing views about scientific and industrial research except the sympathetic interest of an observer for many

*Washington, D. C., August, 1918.

years at rather close range. One looking on comes to realize two things. One is the conquest of practical life by science; there seems to be no department of human activity in which the rule of thumb man has not come to realize that science which he formerly despised is useful beyond the scope of his own individual experience. The other is that science like charity should begin at home, and has done so very imperfectly. Science has been arranging, classifying, methodizing, simplifying everything except itself. It has made possible the tremendous modern development of the power of organization which has so multiplied the effective power of human effort as to make the differences from the past seem to be of kind rather than of degree. It has organized itself very imperfectly. Scientific men are only recently realizing that the principles which apply to success on a large scale in transportation and manufacture and general staff work apply to them; that the difference between a mob and an army does not depend upon occupation or purpose but upon human nature; that the effective power of a great number of scientific men may be increased by organization just as the effective power of a great number of laborers may be increased by military discipline.

This attitude follows naturally from the demand of true scientific work for individual concentration and isolation. The sequence, however, is not necessary or laudable. Your isolated and concentrated scientist must know what has gone before, or he will waste his life in doing what has already been done, or in repeating past failures. He must know something about what his contemporaries are trying to do, or he will waste his life in duplicating effort. The history of science is so vast and contemporary effort is so active that if he undertakes to acquire this knowledge by himself alone his life is largely wasted in doing that; his initiative and creative power are gone before he is ready to use them. Occasionally a man appears who has the instinct to reject the negligible. A very great mind goes directly to the decisive fact, the determining symptom, and can afford not to burden itself with a great mass of unimportant facts; but there are few such minds even among those capable of real scientific work. All other minds need to be guided away from the useless and towards the useful. That can be done only by the application of scientific method to science itself through the purely scientific process of organizing effort. It is a wearisome thing to think of the millions of facts that are being laboriously collected to no purpose whatever, and the thousands of tons of printed matter stored in basements never to be read—all the product of unorganized and undirected scientific spirit. Augustus De Morgan, denying the divinity of Francis Bacon, says "What

are large collections of facts for? To make theories *from*, says Bacon; to try readymade theories *by*, says the history of discovery; it is all the same, says the idolater; nonsense, say we." Whichever it may be, the solitary scientist is likely to put a great part of his life into the pathetic futilities illustrated by De Morgan in the *Budget of Paradoxes*. He needs chart and compass, suggestion, direction, and the external stimulus which comes from a consciousness that his work is part of great things that are being done.

This relation of the scientific worker to scientific work as a whole can be furnished only by organization. It is a very interesting circumstance that while the long history of science exhibits a continual protest against limitations upon individual freedom, the impulse which has called in the power of organization to multiply the effectiveness of scientific and industrial research to the highest degree is the German desire for military world dominion, supported by a system of education strictly controlled by government. All the world realizes now the immense value in preparing for the present war, of the German system of research applied at Charlottenburg and Grosslichterfelde. That realization is plainly giving a tremendous impetus to movements for effective organization of scientific power both in England and in the United States—countries whose whole development has rested upon individual enterprise. It remains to be seen whether peoples thoroughly imbued with the ideas and accustomed to the traditions of separate private initiative are capable of organizing scientific research for practical ends as effectively as an autocratic government giving direction to a docile amd submissive people. I have no doubt about it myself, and I think the process has been well begun in England under the Advisory Council of the Committee of the Privy Council for Scientific and Industrial Research, and in the United States under the National Research Council. I venture to say two things about it. One is that the work cannot be done by men who make it an incident to other occupations. It can be encouraged of course by men who are doing other things, but the real work of organization and research must be done by men who make it the whole business of their lives. It cannot be successful if parcelled out among a lot of universities and colleges, to be done by teachers however eminent and students however zealous in their leisure hours. The other thing is that while the solution of specific industrial problems and the attainment of specific industrial objects will be of immense value, the whole system will dry up and fail unless research in pure science be included within its scope. That is the source

and the chief source of the vision which incidentally solves the practical problems.

We are thinking now mainly of science as applied to war; but practically the entire industrial force of mankind is being applied to war, so that our special point of view takes in the whole field. It is quite certain that if the nations on either side in this war had been without a great fund of scientific knowledge which they could direct towards the accomplishment of specific things in the way of attack and defense, transportation and supply of armies, that side in the war would long since have been defeated. Germany had the advantage at the start, because she had long been consciously making this kind of preparaion with a settled purpose to bring on the war when she was ready. It would be the height of folly for the peaceable law-abiding nations of the earth ever to permit themselves to be left again at a disadvantage in that kind of preparation. Competency for defense against military aggression requires highly developed organized scientific preparation. Without it, the most civilized nation will be as helpless as the Aztecs were against Cortez.

We are not limited, however, to a military objective, for when the war is over the international competitions of peace will be resumed. No treaties or leagues can prevent that, and it is not desirable that they should, for no nation can afford to be without the stimulus of competition.

In that race the same power of science which has so amazingly increased the productive capacity of mankind during the past century will be applied again and the prizes of industrial and commercial leadership will fall to the nation which organizes its scientific forces most effectively.

THE FUNCTION OF SCIENTIFIC RESEARCH IN A MODERN STATE

By Henry S. Pritchett

President of the Carnegie Foundation for the Advancement of Teaching

The part played by scientific reseach in the development of modern nations is so well understood that it is a part of the common knowledge of mankind. What is perhaps not so well apprehended is the relation between the investigator in his laboratory or his library and the industrial and financial machinery through which his research is enabled to develop into forms which increase wealth, sustain human health and activity, and increase the comfort and security of human life. The world still conceives of scientific investigators in much the same light as

the old time prospectors for the precious metals—each individual sinking his shaft here or there as chance or inclination may carry him. Of the great number so engaged a very few will strike veins of true gold, a larger number will obtain ore that will at least repay the labor and cost involved in their adventure, but the great majority will sink holes in barren and fruitless soil.

The prosecution of research today is upon an entirely different basis. Not only do those in the same science coördinate their work, if they are to attain the highest results, but all branches of science are regarded not as separate and unrelated agencies, but as parts of a common effort. A research started in a purely physical field may find its solution in a chemical reaction or a physiological process. The research men of a nation are not isolated individuals but an organized and coöperating army.

A striking illustration of the outcome of this conception is afforded by the history of the great industrial research establishment at Grosslichterfelde outside Berlin. In this vast establishment covering many acres, are brought together research men from every field of science working together in the solution of problems arising in the industries. A problem in textiles, or metals, or sanitation may require the coöperative efforts of men in fields of science that we ordinarily consider as foreign to each other. In the field of industrial research, chemistry, biology, mechanics, physics, are not separated and unrelated sciences, but parts of one universal science.

As a result of this coöperation the German manufacturer may take to this great research laboratory any problem of scientific industry. Manufacturers of steel, brass, stone, textiles, dyes, bring their difficult problems here to be solved. The first act of the administration is to put the enquirer abreast of the literature of the whole world. In many cases it will be found that the problem has already been solved somewhere, oftentimes for a purpose widely different from that of the particular enquiry that has called for the solution.

In the United States the relations between research men in the universities and institutes of research and those operating industrial plants have not yet come to a stage as intimate or fruitful as that which has existed for many years in Germany. It is today a part of our plan of progress for the future to establish such relations that the investigator and the manufacturer shall understand each other and shall coöperate intelligently for the promotion of science and industry.

RELATIONS OF SCIENCE TO INDUSTRY

By Theodore N. Vail

President of the American Telephone and Telegraph Company

It has been my desire to assist the National Research Council in bringing about closer coöperative relations between scientific and industrial effort and the more satisfactory coördination of the various sorts of research activity. I therefore welcome this opportunity to express my convictions concerning the importance of intimate relations between science and industry.

An immense amount of work has been done and is being done for the increase of knowledge through research. Much of this is wholly voluntary and isolated. Large results have followed but little has been accomplished by comparison with what can and will be achieved by the effective organizaton of effort. For such organization will at once reduce duplication of work and increase achievement through coöperation.

Scientific research is at the best costly in time and money because many wildernesses are necessarily explored without important results and many trails which lead nowhere are sure to be followed. But by carefully avoiding a duplication of work and by utilizing all that pioneer investigators have done the fruitfulness of research can be greatly increased. That this fact is recognized and widely accepted is indicated by present efforts toward organization.

What is now urgently needed is a clearing-house which shall be systematically organized to coördinate both scientific and industrial research. All investigators should be kept in intimate touch with such a clearing-house and through it the work of each should be made available to all. It should be one of the functions of this organization to promote the effective distribution and utilization of research information and in other feasible ways to minimize waste and promote the original work upon which progress chiefly depends.

Except for the special laboratories of a few large industrial organizations and the smaller laboratories of individuals, both scientific and industrial research have been carried on in the laboratories of educational institutions by individuals who are at once teachers and investigators. The combination of teaching and research should doubtless be continued, for it is profitable alike to student and teacher and tends to promote both research and scientific training. It is possible on the one hand for students to render valuable research assistance while studying in a col-

lege or university, and on the other hand it is almost inevitably true that contacts of the teacher with advanced students increase his value as an investigator. But already pure research has become so broad in its applications, and so insistently demanded by practical interests, that it constitutes an over heavy burden on educational institutions and must therefore be taken care of in a measure by the provision of special organizations.

Many educational institutions possess large and effectively organized laboratories with excellent staffs. It is not desirable that these organizations be ignored in the further promotion of research. Instead educational institutions should be financially aided in order that they may adequately provide for pure research both by material equipment and by the appointment of investigators whose time is not to any considerable extent demanded for other duties. Research laboratories, whether or not connected with educational institutions, should be freely open to the public and every effort should be made so to exhibit the importance of investigation that it shall be increasingly supported by the public.

The close connection in recent years between industrial progress and what may be called industrial research is significant. The large industrial enterprises have been developed as much through the organization of their scientific departments as through that of their operating departments. These departments of industrial research will undoubtedly be continued along present lines for, while their maintenance is costly in the aggregate, the expenditure is negligible by comparison with practical results when spread over a large production.

Many if not all of the large industries which have developed research departments started when the application of science to their particular needs was new. Consequently the industry and its corresponding research have developed together. But the progress of science during the past half-century has necessitated specialization in research as well as in production, so that today small and novel industries are unable to carry the burden of a highly organized research department. Unless something is done to meet the needs of such industrial establishments, a type of enterprise which has done much to advance civilization and to promote industrial progress will tend to disappear because of the impossibility of competing with larger and well established industrial organizations.

In short, the organization and coördination of research for industrial purposes is urgently necessary. Future progress is dependent upon prompt and wise action. Plans should be formulated at once with care.

Whatever is done should be national in its comprehensiveness and socialistic in its application. All should contribute and all should be able to avail themselves of the benefits of the research clearing house.

There is no question in my mind but that education and industry would greatly benefit by more intimate relations to research and through the promotion of scientific and industrial investigations. Industry may be expected to support generously any organization which promises to effectively coördinate and correlate efforts for the increase of knowledge, since it is now generally recognized that industrial progress and success are chiefly dependent upon knowledge.

COÖPERATION BETWEEN SCIENCE AND INDUSTRY

By Ambrose Swasey

President of the Warner and Swasey Company

The subject of industrial research is one of the most interesting and potentially perhaps the most valuable of all the material questions stimulated by the war.

The use of science in industry is not new in our country, nor in some of the other countries now at war; but the appreciation of the need for scientific and industrial research and the value of it has been tremendously developed by the stress of war conditions.

While it is true that the industrial life of our country has moved forward, during the years of peace, chiefly under the pressure of our needs or the enterprise and aggressiveness of individuals, yet many of our largest and most important industries owe their development principally to an understanding of the need for scientific study of their problems. Prominently among these must be listed the great electrical development in this country—a development based practically entirely upon the work of the scientist and the technician; our steel industry, with its by-product coke plants and all the products related thereto; the automobile industry with its relationship to metals; paints and varnishes; rubber and many other collateral lines; and latterly, the aeronautical field, which promises to lead us into undreamed-of achievements.

Without minimizing the accomplishments of the highly trained technical men in these industries, we can credit the great advances chiefly to scientific research, and the work of the technician, which has made applicable and practical the deductions of the scientist.

In these industries and many others, the study and conclusions of the

scientist have made it possible for the labor of millions of people to be applied in a manner that, only a few years ago, would have been confined to a few specially trained individuals. To be specific, the development of the pyrometer makes possible the use of comparatively untrained workers on heat treatment, which formerly required the maximum of training and experience. The result of it all is to render to mankind those safeguards, conveniences, and comforts which formerly could be possessed only by a few fortunate people, if indeed, they existed at all.

The knowledge of the results accomplished in agriculture by national and state scientific investigation and coöperation is perhaps too widespread to make it necessary even to mention that subject.

The effort of the individual to better his own condition has received its chief aid from science. That the individual may be unaware of this does not alter the fact.

Our present duty is to decide how we shall meet the new situation, with plans wide and broad enough to assure the best results, without relinquishing any of the advance we have earned by years of effort and study.

In all of the countries now engaged in war the need for vastly increased quantities in all lines of production, with the necesssary curtailment in quantity available or change in character of raw material, has necessitated the adoption of new methods. The fundamental elements of each industry have been closely scrutinized, and old methods have given place to new with amazing rapidity. The nations will never resume the old methods; individual effort will continue to play the chief part; but coöperative effort, and to some degree, governmental action in directing and controlling research in industrial fields, has become essential. By no other means could we hope to meet the new world conditions which will follow the war.

If, after the war, other nations were to follow an easy-going industrial policy, it would possibly be a matter of indifference as to our national attitude. We would, however, be blind to the signs of the time if we should fail to recognize that the reverse is certain to be the case. 'Efficient industry' must be the watch-word of the future.

Nations have been stimulated by the war to their utmost endeavor, and science in coöperation with industry has been called upon to help rescue the world.

THE VALUE OF INDUSTRIAL RESEARCH

By A. W. Mellon

President of the Mellon National Bank of Pittsburgh

The recognition of the national essentiality of science, particularly chemistry, to the life of a nation has stimulated the industrialists to such a point that they are seeking at this particular time, as never before, to utilize every idea which makes for the advancement of industry. The aim of all industrial operations is toward perfection, both in process and mechanical equipment, and every development in manufacturing creates new problems. It is only to be expected, therefore, that the industrial investigator is becoming less and less regarded as a burden unwarranted by returns. Industrialists recognize, in fact, that manufacturing is becoming more and more a system of scientific processes; and probably no science has done so much as chemistry in revealing the hidden possibilities of the wastes and by-products of manufacturers. The present great advances are due entirely to the application of knowledge in the development of new things, which is primarily dependent upon systematic industrial research.

The industrialist, however, needs all possible assistance in undertaking and developing research work as a means of enlarging his output and improving its quality. In order to be effective it must increase his independence and initiative, and be so given as to enlist his active support. It has been the coöperation of progressive industry with science which has led to the practical application of the results obtained in the laboratories of scientific men. But, in this matter of the dissemination of knowledge concerning industrial practice, it must be evident to all that there is not complete coöperation between manufacturers and the technical schools. Manufacturers have been quite naturally opposed to publishing any discoveries made in their plants, since 'knowledge is power,' while, on the other hand, the technical schools exist for the diffusion of knowledge and from their standpoint the great disadvantage of the above policy is this concealment of knowledge. It results in a serious retardation of the general growth and development of service in its broader aspects and renders it much more difficult for the technical schools to train men properly for such industries. Fortunately, the policy of industrial secrecy is becoming more generally regarded in the light of reason and more liberal views are taken, which is bringing about a closer union between science and industry. It may, therefore, be taken for granted

that the great corporations all over the country that have entered into such a scheme of coöperation with science have a vivid and comprehensive realization of the need of the efficiency which the scheme represents, and, incidentally, that the scheme itself is founded on sane and practical considerations.

Industrial research is, in fact, a very specialized business and, naturally, requires specially trained men and an understanding on the part of the industrialists as to its requirements and methods. The fundamental differences between pure research and industrial research are, indeed, traceable to the differences in the poise and personality of the representatives of each type of scientific investigation. Success in genuine industrial research presupposes all the qualities which are applicable to success in pure science, and, in addition, other qualities, executive and personal, more or less unessential in the pure research laboratory. At this point enters the real value of a system of coöperation between science and industry; the industrialist is aided by being taught the correct methods to follow and by guidance in the selection of the proper type of research men to carry on his work.

The individual manufacturer is not the only one to be benefited through well-established central research laboratories; as a general policy, 'Service to Industry' is exceedingly well carried out through work for associations, as the one laboratory is thereby enabled to serve practically all the manufacturers in any particular field at a very low cost to each manufacturer, and the benefits are received by some industrialists who otherwise would not feel able to support independent research work.

Manufacturers who have benefited by the application of science to industry have not been content to await chance discoveries but have established well equipped laboratories and strong research staffs. Moreover, some large industrial corporations have found it expedient to keep before the public the fact that investigations on a large scale ultimately bring considerable benefit to the community generally; that every scientific discovery applied in industry reacts to the public gain; and that consequently great industrial organizations are justified in the expenditure of large sums of money to carry on such investigations, since it is only where there are large aggregations of capital that the most extensive and productive research facilities can be obtained.

A spirit of coöperation should be encouraged among all types of research laboratories, as no greater good to society can arise than from a wider distribution of the duties and responsibilities of research. Accordingly, well established research laboratories should be willing to coöper-

ate and render informative service necessary for the establishment and organization of other research laboratories.

We are now passing through a period which clearly brings to mind the fact that civilization unarmed by science is at a terrible disadvantage in a struggle for existence; and we must realize that this arming cannot be done at short notice.

CONCERNING THE IMPORTANCE OF INDUSTRIAL RESEARCH

By George Eastman

President of the Eastman Kodak Company

In the reorganization and readjustment of industry to the needs of the present time the extension of scientific research must play a great part. In recent years the application of research to industry has increased very greatly and manufacturing concerns of all kinds have organized research laboratories. These laboratories have up to the present been considered chiefly as auxiliaries to the producing departments. A business which established such a laboratory hoped to derive some direct benefits from the research work undertaken, to develop new products, to lower manufacturing costs, to overcome difficulties that arise. These hopes have generally been justified by the results that have been achieved, but it seems probable that the greatest value of industrial research lies rather in the indirect than in the direct benefits which flow from the association of science and industry.

Recent events have enabled us to realize that the effectiveness of an industrial organization depends upon knowledge, not only scientific knowledge but technical, commercial and financial knowledge, and the problem before us in developing our industry further is to arrange for the creation and distribution of wider knowledge in all departments.

By the very nature of its work an industrial research laboratory must become a focus and center of the technical knowledge of the industry. In our schemes for industrial development, therefore, we must direct our aim so that the laboratories established for research may create and systematize the technical knowledge relating to the industries with which they are associated, so that from the laboratories this knowledge may permeate all branches and sections of business life, raising the standard of aim and achievement alike in the manufacturing and commercial sides of industry, insisting on products of higher quality and simultane-

ously educating customers to make the best use of the products which are supplied to them.

Only by research and the systematic development of knowledge can we hope to attain to the true increase of wealth, an increase which affects the comfort and happiness of employed and of employer alike.

THE SIGNIFICANCE OF RESEARCH FOR MINING AND METALLURGY

By Walter Douglas

President of the Phelps Dodge Corporation

The extreme importance of industrial research in the successful conduct of great mining and metallurgical enterprises can be appreciated when it is realized that upon the development of certain scientific methods depends the commercial success of the production of metals from ores formerly regarded as valueless. The efforts of producers are directed toward economical means of extracting coal and metalliferous ores with the least possible loss consistent with safety to the miner, and the concentration and beneficiation of the raw material in such manner as to obtain the highest extraction of the valuable content. To this end, scientific investigation and experimentation are essential, and nearly all great, forward steps in industrial and technical advancement have originated in the research departments of the large producing companies. At this time, with foreign sources of supply of certain important elements curtailed through shortage of vessels, it is of special importance that means be devised to furnish certain substitutes or to utilize our own raw materials through the invention or perfection of processes by which production of commercial grades can be made available. Never before have the departments of industrial research assumed such importance to the basic industries of this country as they do today, and if we are to make ourselves independent of materials for which we have in the past relied on Germany, we must enlarge and elaborate our departments of research and investigation to an extent considered in the past as unnecessary and unjustified.

THE APPLICATION OF SCIENTIFIC RESEARCH TO ONE INDUSTRY

By JAMES R. MACCOLL

TREASURER OF THE LORRAINE MANUFACTURING COMPANY

It must be frankly admitted that in many industries the importance and value of scientific research have not been adequately grasped.

In the textile industry (particularly wool and cotton) twenty years ago there were probably no concerns large enough to carry on independent scientific research on a broad and liberal scale. In recent years, combinations have been formed—under one control—of groups of mills, and it would certainly be advantageous and profitable for these large concerns to make a liberal appropriation for scientific research, employing for this work men of ability who combine scientific training with sound, practical business ideas.

In addition, however, to these independent efforts, it would be of great benefit to the industry if there could be a coöperative movement organized by the National Research Council along with the leading textile schools and a committee of manufacturers to develop and supervise research and experiment in laboratory, textile school and factory.

The field is a broad one, beginning with the raw materials through all the processes of yarn-making, weaving, dyeing, printing, and finishing. It is a fact worthy of note at the present time that there is a large supply of faulty wool and low-grade cotton which can be purchased at relatively low prices compared with the better classes of wool and cotton which are in demand and in short supply. Here is a profitable field for research, and it is only one of many that could be enumerated.

The concentration of scientific minds upon research and experiment would undoubtedly be of vast benefit to the textile industry and to the welfare of mankind.

THE ORGANIZATION OF SCIENTIFIC AND INDUSTRIAL RESEARCH AT HOME AND ABROAD

By H. E. Howe

Vice Chairman, Division of Industrial Research, National Research Council

I. GENERAL STATEMENT

Research is not merely the collection of existing facts and data on a given subject; that is but an incidental though important phase of the work. One type of research creates new knowledge and gives new power over materials; the other type seeks to apply this newly created knowledge to the solution of specific problems. The two are really interdependent, equally complex and necessary.

For a number of years the world has been gradually developing a better appreciation of the scientific method and of scientific research largely because the benefits derived through its application to industry have been strikingly demonstrated. There are many examples of the commercial value of researches begun in pure science with no idea of immediate industrial application. Research therefore has been encouraged more and more, resulting in many discoveries of scientific and practical importance.

War is always a combat between two or more groups of resources and the most efficient utilization of these resources requires the proper application of science. This in turn involves the coördination of all facilities for research and applied science and frequently it has been shown that many serious difficulties were traceable to the failure to employ research previously. War has given great impulse to nearly all branches of science and one of our duties is to maintain and increase the momentum which has been gained.

Many of our war problems are associated with peace problems. Methods of manufacture, materials employed, principles to be mastered, are quite similar whether the product is one of peace or war, so that throughout the world it has come to be realized that we must continue to encourage, stimulate, and increase research in both pure and applied science if for no other reason than that we may make more and better things, understanding why as well as how it is done.

Attention is called to the present status of this world-wide movement,

II. UNITED STATES

In 1863, President Lincoln approved an act of Congress, incorporating fifty of the country's leading scientists under the designation of the National Academy of Sciences. One of the functions of the Academy was "to investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any government department, but the Academy was to receive no compensation whatever for such services. The Academy served well during that emergency and on many later occasions has rendered valuable service to our government. Its by-laws have been modified at times and the number of its members increased.

In April, 1916, the Academy through its president offered to organize the scientific research of the country and the President of the United States accepted the offer and later approved the formation of the National Research Council, a body created to carry on this work. Later the Council was requested to act as a Department of Science and Research of the Council of National Defense, to organize a Science and Research Division of the Signal Corps and to carry out many other commissions for the military and naval establishments.

In order that the numerous problems might have the intensive study of specialists, the Council was organized along divisional lines, each division being composed of sections and special committees, upon which many of the country's foremost scientists served. The officers of the Council, the chairmen and vice-chairmen of divisions, and the chairmen of the sections of the General Relations Division, together with the elected members, made up an executive board which was assisted in its work by an interim committee. The divisions under the war organization were those of general relations, military, an important part of which was the research information service, engineering, physics, mathematics, astronomy and geophysics, chemistry and chemical technology, geology and geography, medicine and related sciences, agriculture, botany, forestry, zoölogy and fisheries.

Even a brief outline of the work accomplished could not be given here. Some of this work was done by the members themselves, some in laboratories throughout the country, and some in a purely advisory capacity, the Council or its sub-divisions acting as a clearing-house for information and helping to secure the necessary coöperation.

On May 11, 1918, the President issued an Executive Order in which it was stated that "the work accomplished by the Council in organizing research and in securing coöperation of military and civilian agencies

in the solution of military problems, demonstrates its capacity for larger service." It was further requested that the National Research Council be perpetuated with duties which were set forth as follows:

1. In general, to stimulate research in the mathematical, physical and biological sciences, and in the application of these sciences to engineering, agriculture, medicine and other useful arts, with the object of increasing knowledge, of strengthening the national defense, and of contributing in other ways to the public welfare.

2. To survey the larger possibilities of science, to formulate comprehensive projects of research, and to develop effective means of utilizing the scientific and technical resources of the country for dealing with these projects.

3. To promote coöperation in research, at home and abroad, in order to secure concentration of effort, minimize duplication, and stimulate progress; but in all coöperative undertakings to give encouragement to individual initiative, as fundamentally important to the advancement of science.

4. To serve as a means of bringing American and foreign investigators into active coöperation with the scientific and technical services of the War and Navy Departments and with those of the civil branches of the government.

5. To direct the attention of scientific and technical investigators to the present importance of military and industrial problems in connection with the war, and to aid in the solution of these problems by organizing specific researches.

6. To gather and collate scientific and technical information at home and abroad, in coöperation with governmental and other agencies and to render such information available to duly accredited persons.

On a peace basis the Council's organization will be slightly different from the war time plan. It will consist of three classes of representatives: first, those of national scientific and technical societies; second, representatives of the government; and third, those of other research organizations and individuals whose aid may serve to advance the objects of the Council. The division method of organization will be followed with two principal classifications, (a) divisions concerned with the more general relations and activities of the Council, and, (b) those dealing with related branches of science and technology. Under the first class there will be six divisions; namely, government relations, foreign relations, states relations, educational relations, industrial research, and research information service. The divisions of science and technology will be seven in number; namely, physical sciences, engineering, chemistry and chemical technology, geology and geography, medical sciences, biology and agriculture, and anthropology and psychology.

The purpose of the Council may be stated as the promotion of research in the mathematical, physical and biological sciences and in the application of these sciences to engineering, agriculture, medicine and other useful arts, with the object of increasing knowledge, of strengthening the national defense, and of contributing in other ways to the public welfare, as expressed in the Executive Order quoted above. In carrying out this purpose, the Council endeavors in nowise to duplicate the efforts of other scientific bodies and strives to utilize to the fullest extent existing facilities for the prosecution of research, establishing laboratories only where no other course can be followed. A partial list of the non-military problems engaging the attention of the National Research Council is given in Appendix 1, page 33.

The National Research Council also endeavors to encourage research workers and to do what it can to increase the number of such workers in the country. To this end it has been entrusted with a fund of $500,000 by the Rockefeller Foundation, to be expended over a period of five years in the form of National Research Fellowships in chemistry and physics. It is hoped that these fellowships will make it possible to confirm a number of the most promising workers in research by enabling them to continue their research work immediately after taking their doctorates, at which time it is believed they are best qualified to continue any fundamental research. Some twelve appointments had been made at the time this was written, and with the return of large numbers of men to the universities and colleges, it is expected that a considerably larger number of appointments will be made in another year.

It will have been noted that the Council recognizes the importance of research in pure science and the application of the knowledge so acquired to the industries. Clearly one of its most useful activities will be that in connection with industry in which it hopes to promote a deeper sympathy for and appreciation of research.

III. THE BRITISH EMPIRE

a. Great Britain

Perhaps the outstanding difference between the National Research Council of the United States and the corresponding organizations elsewhere is that whereas foreign councils and departments, including the Department of Scientific and Industrial Research of Great Britain, are integral parts of their respective governments, the National Research Council enjoys the unqualified approval and full coöperation of the

United States Government, without being a part of the government organization.

In Great Britain the purposes to be accomplished are essentially the same as those in the United States, but there the government sets itself the problem of encouraging and organizing scientific research by direct state action.

In July, 1915, a committee was appointed by the Privy Council for the purpose of directing the application of any money provided by Parliament for the organization and development of scientific and industrial research, and an advisory council was created for the purpose of reporting and recommending proposals for research work as well as for initiation of proposals. In November, 1916, a charter of incorporation was granted to what is known as the Imperial Trust for the Encouragement of Scientific and Industrial Research, this trust having been established essentially to facilitate the work of handling money provided by Parliament and administering any other property or funds which may come into its possession. In December, 1916, the work of the committee first appointed was established under a separate department of state which has since been known as the Department of Scientific and Industrial Research. This department is responsible to a Minister of the Cabinet; namely, the Lord President of the Council because he is the only minister who has relations with the whole British Empire and it is recognized that if research is to be organized efficiently, it must concern the whole empire and that it ought to be possible to coöperate easily with similar departments or councils in other parts of the empire.

The field of work undertaken may be considered under three heads: first, the encouragement of research workers; second, the organization of research by industries; and, third, the organization of national research.

With respect to encouraging research workers, something over £3500 was spent during the academic year of 1916–1917 to assist those who had acquired enough knowledge to begin research or had shown some special capacity for such investigation. The amount spent in a similar way during 1917–1918 was £7500, and in 1918–1919 approximately £10,000. It is anticipated that this sum will amount to £30,000 during the next academic year. Careful records are kept of the performance of workers recommended by professors and others so that in the future their recommendations may be properly rated. The grants made are of four classes: first, for maintenance to enable students to be trained in methods of research. These are usually made for one year and are renewable for a second year. Second, for assistance to independent workers who

devote their whole time to research whether in pure or applied science. These grants are also made for one year, but may be renewed for a further term of four years. Third, grants to teachers engaged in research to enable the employment of suitable assistants in research but not to act as teaching assistants. Fourth, allotments in special cases to a worker investigating some new branch of science to enable a research lectureship to be established pending the securement of endowment from other sources.

The Department of Scientific and Industrial Research has been particularly active in the organization of industrial research and has been provided by Parliament with a fund of £1,000,000 to enable it to encourage the industries to undertake research. A general policy has been adopted of allotting pound for pound to approved research associations which will engage in industrial research upon approved problems. The intention is to strengthen such research associations and assist them over the initial five year period, after which it is contemplated that the associations will be so firmly established that further government aid is not likely to be required.

These associations are usually limited to those concerns in a given industry or closely related to it or to various industries interested in the same problem or material but non-competitive. The Department gives whatever assistance it can to these associations, acts in an advisory capacity, serves as a clearing-house for information, and takes an active part in the prosecution of work without interfering in any way with the policies of the association.

Four associations are already at work, approximately fifteen more are completing their organization, and eleven others are in the earlier stages of formation. See Appendix II, page 37.

The organization of national research has gone forward along several lines and the Department has acted as a clearing-house of information for the various industrial research associations formed, has conducted investigations for other departments of the state, and has been active through research boards on problems, the solution of which belongs more to the government than to any private group. The investigations undertaken for other state departments have been at the invitation of the department interested, for the Department of Scientific and Industrial Research never knowingly enters a field in which work is under way without proper arrangements with those already concerned in that field. Among the investigations may be noted the question of mine rescue apparatus, and researches with reference to building materials, including home-grown timber.

Among the research boards the first to be established was that on fuel, and the government is spending large sums annually in the investigation of this very important problem. A special laboratory has been erected and it is in charge of a carefully organized staff of specialists. Later a food investigation board was formed, and then one on industrial fatigue research.

Early in 1918 the government assumed responsibility for the National Physical Laboratory, which corresponds, in a way, to the Bureau of Standards of the United States, and the growth of the Laboratory during the war can be best illustrated by comparing the total income of the Laboratory in 1913–14, when it was a little less than £44,000, with the budget for 1919–20 which is nearly £155,000.

Great Britain has proceeded vigorously with its research plans and a large number of important researches have been conducted through various agencies. Among these problems may be mentioned: optical and other scientific glass; tin and tungsten; tool steel; properties and composition of alloys; corrosion of non-ferrous metals in sea-water; refractories; hard porcelain; transformer and switch oils; treatment of high-speed steel; improved design of the cooling surfaces of aircraft motor cylinders; degumming of silk; deterioration of structural materials in sea water; various problems relating to dyeing; studies on fire prevention; investigation of the heating of buried cables; preliminary study of the flow of steam through nozzles; and the deterioration of super-heaters operating at high temperatures.

Some of the work which has actually been done is given in greater detail in Appendix II, page 36.

b. Australia

The Commonwealth Advisory Council of Science and Industry was established in March, 1916, and its purpose was the preparation of ground for the proposed permanent Institute of Science and Industry and starting the work of that permanent Institute. The preliminary work involved a census of Australian industries and of the problems connected with them; of the equipment and personnel of laboratories; of the research in actual progress; and of the facilities available for training men in scientific investigation. Relations were established with other state departments, with various educational institutions and scientific societies, and with the industries concerned. An effort was also made to encourage and coördinate the researches already in progress. A large number of special committees were appointed, most of which have now

filed their final reports. The work covered by these committees was very diverse and the problems undertaken included: ferro alloys; yeast and bread-making; damage by insects to grain in storage; electrical sterilization of milk; utilization of native barks for tanning; alcohol fuel and engines; development of a mechanical cotton picker; substitutes for tinplate; utilization of kelp; cold storage problems; tuberculosis in stock; by-products of wool-scouring; and a classification of imports of chemicals.

In July, 1917, a detailed plan for the permanent Institute was approved, and it was recommended that a permanent Institute should be established at once to undertake research, standardization, and the establishment of a bureau of information. While existing laboratories are to be utilized as far as possible, it is recommended that at least five national laboratories be established. These are: Plant Industry; Animal Industry; Industrial Chemistry and Metallurgy; Industrial Standards; and Forest Products.

The control of the permanent Institute is to be in the hands of three salaried directors, one of whom is to be a business man, the other two being chosen because of their scientific attainments. Each state of the Commonwealth is to appoint an Advisory Council and the Directors of the Institute are to meet each Advisory Council at least annually. The staff of the permanent Institute is to be appointed by the Governor-General on the recommendation of the Directors.

c. Canada

In June, 1916, the Privy Council of Canada appointed a committee to have charge of all measures relative to the scientific development of Canadian industries. Under this committee an Honorary Advisory Council for Scientific and Industrial Research, composed of eleven members, was constituted November 29, 1916, and established by Act of the Dominion Parliament in August, 1917. At that time $91,600 was voted for the fiscal year, and of this amount $12,000 was to be devoted to studentships and $5000 for fellowships in the educational institutions of the Dominion. To special problems $25,000 was assigned, and a preliminary grant of $600 was made for forest studies.

The plan is similar to that adopted in England. The administrative chairman is a permanent, salaried officer. The Council has charge of all matters affecting scientific and industrial research in Canada, assigned to it by the Sub-Committee of the Privy Council, and advises on questions of scientific and technological methods affecting the expansion of Canadian industries and the more efficient utilization of the natural

resources of the country. The Council works in coöperation with various associations of scientists and manufacturers, and endeavors not only to encourage students to engage in research but to remain in the Dominion in industrial research.

The work in process is of a varied character, carried on principally by associate-committees in chemistry, mining and metallurgy. Upon these committees many scientists, government officials, and industrial men serve; in addition, British Columbia has appointed an Honorary Advisory Committee to coöperate with the Council. Council committees have been appointed to deal with such special problems as: hydro-power development; potash and phosphates; and temporary committees have undertaken the study of flax cultivation; cold storage; Fraser River salmon questions; plant and animal diseases; underground waters for the western plains. At the moment special attention is being given to the utilization of lignite through briquetting and otherwise.

The report of the Associate Committee on Chemistry for the year ending May 1, 1918, discusses seven major problems which the Committee had under consideration and a considerable list of special inquiries to which attention had been given. The researches assisted by the Council were ten in number.

The Council is now active in obtaining the establishment of a research institute similar to the Bureau of Standards of the United States, and has been granted some $400,000 for the continuation of the lignite studies. A census of the research facilities and the research man-power of the Dominion has been made and active steps are being taken to interest industries in the prosecution of research.

d. India

During the war the Indian Munitions Board stimulated industrial enterprises involving scientific and technical knowledge, and particularly those of direct value for modern warfare. It is the intention of the government that after the war this work will be carried on by an industrial board or department of the government in succession to the Munitions Board.

The Munitions Board pointed out that "munitions for a modern army cover practically all the ordinary wants of a civil community," and much has already been done to stimulate the tanning and textile industries, metallurgy, the manufacture of chemicals and of machinery, besides a number of miscellaneous undertakings.

e. New Zealand

Several proposals have been made looking to the organization of scientific and industrial research in New Zealand, and reports upon the subject are understood to be receiving the careful consideration of the government. The General Council of Education has prepared a plan for the adaptation of the educational system to the development of New Zealand resources. The plan provides for the establishment of a National Advisory Council on Research with four specific duties:

1. To allot all proposals for specific researches to the proper persons.
2. To study problems pertaining to particular industries and to determine the lines along which research shall proceed.
3. To award National Research Fellowships and Scholarships.
4. To advise the General Council of Education with reference to bringing about a general improvement in scientific education in order that specialists may be trained, and a better appreciation of the aims and advantages of science be obtained among producers, manufacturers, and the people generally.

f. South Africa

The South African Government has appointed an Industries Advisory Board. This was established in October, 1916, the members being almost entirely representatives of commerce, manufacturing and labor. In February, 1917, this Board recommended the appointment of a Scientific and Technical Advisory Committee to deal with all scientific and technical matters and questions of research which would be referred to them by the Industries Advisory Board. A committee of ten members was accordingly appointed, and this committee has undertaken, in addition to providing for industrial research, to coördinate industrial investigations and research in South Africa, and to collect and disseminate data emanating therefrom. They also undertook coördination with other government departments and with similar departments of the United Kingdom to obtain available information, to avoid duplication, and to take advantage of facilities for research not available in South Africa. An economic survey of natural resources, and advice relating to the best methods of their utilization; advice relative to methods of attacking industrial problems; the coördination of various industries and the exchange between user and manufacturer of improvements and experience, were among their other activities. Educational work, including lectures, publications and museums, and the standardization of scientific and industrial qualities affecting the efficiency of production and the accuracy of statistics, have also had their attention.

IV. FRANCE

In France the progress in the establishment of a national council has not been as rapid as elsewhere. The question of national laboratories of scientific research was made the subject of a report by a committee of the Paris Academy of Sciences in November, 1917. France has had no institution corresponding to the Bureau of Standards of the United States, the National Physical Laboratory in England, or the State Laboratories in Germany, and the Academy of Sciences, being convinced of the necessity of organizing systematic scientific researches in France, expressed its wish that a National Physical Laboratory should be founded for the prosecution of research useful to the progress of industry. The Academy suggests that such a laboratory should be placed under its control and direction working through a Council, one-half of whose members would be nominated by the Academy, one-quarter representing the State Departments, and the remaining delegated by industrial interests.

A school for applied optics, supported by a combination of government and private funds, has been established for the purpose of stimulating the study of optics and the manufacture of optical instruments.

V. ITALY

Early in 1916 the Office of Inventions and Research was created as a Department of the Ministry of Arms and Munitions and was organized under Senator V. Volterra. That Office served with distinction during the war and an Italian National Research Council is now in process of formation. Its objects will be:

(a) To further researches in the sciences and in the application of these to industry, agriculture, hygiene, alimentation and to national defense.

(b) To formulate and accomplish concrete projects of researches, in order to utilize the scientific, technical and natural resources of the country.

(c) To furnish technical or scientific information as required by public administrations and perform experimental and theoretical researches as asked for by the same administrations.

(d) To establish constant liaison by means of Italian and foreign delegates (Scientific Attachés to the Embassies) with similar foreign institutes so as to furnish information on the scientific and technical work of foreign countries and promote, in this way, researches and associations of international character.

(e) To furnish to the Army and Navy scientific, technical and industrial data relating to the national defense.

The Council will be divided under seven general headings as follows: (a) mathematical sciences and sciences of observation and measurement;

(b) mechanics and engineering; (c) physics and its applications; (d) chemistry and its applications; (e) aerodynamics and its applications; (f) mineralogy, geology and mining; (g) biological sciences and their applications especially those relating to agriculture and technical zoölogy.

In addition, there will be divisions especially concerned with national defense, patents, and coöperation with other countries. The Council will be made up of representatives from various State Departments, representatives of scientific and industrial bodies and unattached individuals. It is intended to use existing research facilities in educational and industrial plants, but also to establish special laboratories if need is found for them. It is expected that the government will appropriate a million lira for the support of the work of the Council, this being added to the budget of the Minister of Industries. Under this Department the Council will carry on its work.

VI. JAPAN

In Japan steps have been taken for the establishment of a National Laboratory for scientific and industrial research, the National Physico-Chemical Institute of Japan. The work of this laboratory will be the development of Japanese industries through the application of modern methods and the results of researches which are to be undertaken. The various sections of the laboratory will be devoted to such subjects as the following: (a) electricity and electro-chemistry; (b) lighting; (c) scientific apparatus; (d) drugs, dyes, perfumes, rubber, etc.; (e) artificial or imitation silk; (f) foodstuffs and beverages; (g) refrigerating methods; (h) oils; (i) fixation of atmospheric nitrogen; (j) utilization of fumes for metallurgical works; (k) prevention of explosions in coal mines; (l) microscopic research with iron and steel; (m) steam turbines; (n) resistance, power, and speed of ships; (o) arms and ammunition; (p) fire-proof and earthquake-proof buildings. Young men of promise in research are being appointed to fellowships and sent abroad.

Approximately two and a half million dollars has been set aside to support the laboratory over a period of ten years. Control will be placed in the hands of a General Council consisting of fifty members and the organization is to be made a part of the Department of Agriculture and Commerce.

VII. BELGIUM

The establishment of a National Research Council is under consideration by the Belgian Government.

VIII. INTERNATIONAL RESEARCH COUNCIL

Through the initiative of the National Academy of Sciences—particularly its Foreign Secretary, Dr. George E. Hale—a plan has been perfected for the establishment of an International Research Council, to be composed of representatives of the Research Councils or similar bodies in the allied and neutral countries. This international body will have a vice-president for each country represented, and will be organized upon divisional lines very much as the National Research Council of the United States is now organized. It will consider principally those problems which have international importance, such as certain questions in astronomy, geophysics, medicine and related sciences. It will also serve to disseminate knowledge and coördinate much of the research undertaken by various organizations in different parts of the world in such a way that greater progress seems certain. At the meeting held in Brussels in July details of arrangement were perfected and the various divisions will shortly announce their organization and program for work. It is contemplated that the International Research Council will perform the functions of some of the international associations which have heretofore been in operation.

IX. APPENDIX 1

Partial list of non-military researches undertaken by the National Research Council:

Engineering Division

Pyrometer.
Making of steel ingots.
Fatigue of metals.
Saving of manganese.
Electric welding.
Improvement of metals at blue heat.
Elimination of inclusions from steel.
Elimination of sulphur in open hearth practice.
Electric insulation.
Hardness testing machine.
Neumann bands.
Production of metallic beryllium.
Pulverizing.
Standardizing of bearing metals.
Substitute oxidizers.
Uses of alloy steels.
Uses of tellurium and selenium.
Uses of cadmium.
Airplane motors.
Carburetors.

Airplane fuels.
Locking differential for motor trucks.
Walking-beam tractor.
Airplane propeller.

Division of Chemistry and Chemical Technology

Chemical properties of the following:
- Soils.
- Fertilizers.
- Rubber and allied substances.
- Fuels and combustion.
- Ceramics.
- Synthetic drugs.
- Dyestuffs and textiles.
- Colloids.
- Nitrogen fixation.

Sewage disposal.

Division of Medical Sciences

A. Under direction of the Executive Committee of the Division:
- The development of protectors for the ear against effects of high explosives.
- New methods for the production of acetone.
- General testing of new antiseptics and special study of application of the same.
- Studies of anaerobic bacteria of importance in war wounds.
- The cultivation, collection and pharmacological study of native medicinal plants.
- Determination of substitutes for ambrine.
- A study of gases as disinfectants of wounds and their use to render disease carriers innocuous.
- Sterilization of drinking water for large bodies of troops.
- A critical study of methods of small-pox vaccination on a large scale.
- The value of the agglutination test after vaccination against typhoid fever.
- A study of rare and unusual sugars in the different strains of pneumococcus, streptococcus, and meningococcus.
- A study of hemostatic preparation.
- Studies of peripheral nerve injury and repair, with special reference to the prevention of amputation neuromata.
- Studies of streptococcus infection, with special reference to empyema.
- A study of possible substitutes for the petri dish.
- War edema among infants.
- Chemotherapeutic studies of experimental pneumococcus infection.
- Tests to devise a gauze mask effective in the prevention of droplet infection.
- A study of the cause of the so-called Spanish influenza and its possible prevention by vaccination.
- Studies on transmission of measles.
- Tests of the influence of slow intravenous injections of foreign serum in the prevention of anaphylactic shock with special reference to the army use of antitoxic sera.
- Chloralose as a general anesthetic in cases of shock.
- Skin grafting as conditioned by the blood group of donor and recipient.
- The use of "immunized" skin grafts in infected wounds.
- Gentian violet as an antiseptic for "preserved blood" used in transfusions.
- Methods to increase the yield of serum-antibodies in immunized animals.
- A simplified and improved apparatus for transfusions.

A study of the importance of antiagglutinins for transfusion.
A test to disclose oxygen-lack in the air of submarines and mines.

B. Committee on industrial poisonings:
  An experimental study of toxic effects of substances entering into the manufacture and handling of explosives.
  A study of early signs of intoxications among munitions workers.
  A study of airplane "dopes."
  The development of protective varnishes or other skin coverings.

C. Committee on toxicity of preserved foods:
  Studies of canning and other methods of preserving food.
  The related problems of botulism.

D. Committee on neurology and psychiatry:
  An analysis of 13,000 records of soldiers discharged from service on account of nervous and mental disturbances.
  The early histological lesions of meningoencephalitis. (From material of the Army Medical Museum.)

E. Committee on the study of the physiology of shock:
  Twenty-nine studies in 10 stations.

F. Committee on control of hemorrhage.

G. Committee on fatigue in industrial pursuits:
  An investigation of hygienic conditions in industrial establishments.
  Studies of industrial efficiency.
  Physiological studies of fatigue.

H. Committee on Biochemistry:
  Studies of varieties of velvet bean and of its utilization as a food.
  Substitutes for cane sugar.
  The minimum vitamin requirement.
  Substitutes for acetone in extracting and drying.

I. Anthropology committee:
  A study of central European races in New York City.
  Race in relation to physical conditions and fitness for employment.
  Anthropometric study of drafted men.

J. Psychology committee:
  Twenty studies by 12 different observers (or groups of observers) of military problems to which the methods of psychology are applicable.

K. Medical zoölogy:
  Studies of Giardia Microti.
  The treatment of experimental Giardiasis.
  An improved method of detecting ova of parasites in stools.
  Hookworm investigations.
  Louse investigation.

Division of Biology and Agriculture

Studies of native woods.
Fertilizers.
Poultry Feeding.
Protein metabolism in animal feeding.
Rats, mice and rodent pests.
Salt requirements of cultivated plants.
Sizing materials.
Salting fish in southern climates.
Lac and lac insects.

X. APPENDIX 2

In order that work actually accomplished may be contrasted with what has been proposed, we invite attention to the following details with reference to the success of the Department of Scientific and Industrial Research in Great Britain.

The first report calls attention to the following researches which had enjoyed the aid of the Department. Laboratory glass; optical glass; refractory materials; hardness testing for journals and pins; properties and composition of alloys; flow of steam through nozzles; heating of buried cables; properties of insulating oils; tool steel experiments; methods of notched bar impact testing; corrosion of non-ferrous metals; hard porcelain; setting and disintegration of salts and crystalline substances; degumming of silk; tin and tungsten; deterioration of structures of timber, metal, and concrete in sea-water; rate of heat transmission from hot surfaces to fluids over them; and statistical work in preparation of field for research in iron and steel.

Much of this work is carried on in educational institutions, in the National Physical Laboratory, and in certain private laboratories. The rapidity with which plans for the promotion and application of research developed is readily illustrated by the breadth of the program outlined in the second report, which announced the million pounds set aside by the government for trade research associations. The work of the Fuel Board, outlined in that report, involved taking stock of the coal resources of each district in Great Britain, classifying the seams according to their qualities, and ascertaining particularly the industrial uses to which the different kinds of coal were being put or in what way they could best be utilized. Peat has also received careful attention with reference to the bogs in Ireland and the most efficient methods of digging, preparing, and using peat for fuel and other purposes. The Board further gave advice as to the standards of quality for town gas and assisted the various Departments of State interested in the supply of fuel of various kinds and its most effective use. Better methods of domestic heating and improvement of ventilation of dwelling houses has formed another phase of the Fuel Research Board's activity, and five researches on domestic heating have been carried out at University College, London. An effort has been made to establish coefficients of heat transmission through standard building materials and to conduct investigations on heat transmission from radiators.

Another field of endeavor has concerned atmospheric pollution and the causes producing it, its effects on public health, buildings, etc., and the value of various means of counteracting it.

Mine rescue apparatus has received special attention, and careful inquiry has been made into types of breathing apparatus used in coal mines, and experiments have been conducted to determine the advantages, limitations, and defects of the several types of apparatus with a view to improving them if possible. Conditions in deep and hot mines have received attention with reference to the influence of hot and moist atmosphere on miners and the possible methods to be employed for cooling and drying the atmosphere in deep mines.

The Concrete Institute, with the aid of the Department, has undertaken a series of carefully regulated tests of concretes made from various local aggregates, the researches being conducted at nine colleges and universities.

A new institute of technical optics has been formed, and because of the deficiency of books in the English language on geometrical and technical optics, a new series of optical text books in English has been initiated.

Surveys of resources have been made, and of the fields for research, and the plan for the formation of coöperative industrial research associations has met with marked encouragement.

Some thirty industries have taken steps to establish these research associations. Three have been licensed, namely, the British Photographic Research Association, the British Scientific Instrument Research Association, and the British Wool Research Association. In addition to these, the cotton industry, the Portland cement manufacturers', the India rubber manufacturers', and the motor and allied manufacturers' research associations are approaching completion. Among other branches of industry which are engaged in drafting articles for the respective associations may be mentioned pottery, mining, iron manufacture, non-ferrous metals, baking and silk.

All of these associations with the exception of the iron manufacturers are being formed on the general plan of the government sharing the expense of the work equally with the association, but in the case of the iron manufacturers they have subscribed all of the necessary funds, and by avoiding any claim upon the government for assistance in their finances, they avoid that measure of regulation which is inseparable from the use of government funds. The Iron Manufacturers' Research Association proposes that not only shall all the results of the researches undertaken be freely available to each firm, but that all existing knowledge, trade secrets, and processes shall be pooled for the common good of the trade. This is a policy which some associations will hesitate to

adopt, but it is expected that much of profit will be derived from the policy.

Inasmuch as these associations are formed to work without paying a profit, the Board of Inland Revenue has instructed the Surveyors of Taxes to allow as a working expense for income tax purposes the contributions made to industrial research associations formed for the purpose of scientific research for the benefit of the various trades. There are certain safeguards, but since this decision includes war profits and excess profit taxes, it offers a considerable inducement to firms affected by these taxes to join such associations promptly and support them in a substantial manner.

An excellent example of the thoroughness with which the preliminary work in the formation of such research associations has been conducted is the British Cotton Industry Research Association. In that instance an excellent booklet has been issued calling attention to the dependence of the cotton industry upon research for its further progress, and pointing out that in no other way can English manufacturers hope to maintain the lead in the cotton industry. Emphasis is placed upon the fact that whereas we insure against all sorts of financial loss and calamity, in most instances the manufacturer and the industry are not adequately insured against greater losses due to ignorance, and that such insurance can be had only by consistent and continued support of scientific and industrial research.

XI. APPENDIX 3

Below is quoted the Memorandum of Association which has been suggested by the British Department of Scientific and Industrial Research for the use of those forming research associations.

MEMORANDUM OF ASSOCIATION OF THE BRITISH RESEARCH ASSOCIATION

1. The name of the Association is 'The British Research Association.'
2. The registered office of the Association will be situate in England.
3. The objects for which the Association is established are:—

(a) To promote research and other scientific work in connection with the . . . . trade or industry and other trades and industries allied therewith or accessory thereto, and for that purpose to establish, form, equip and maintain laboratories, workshops or factories, and conduct and carry on experiments, and to provide funds for such work, and for payment to any person or persons engaged in research work, whether in such laboratories or elsewhere, and to encourage and improve the education of persons who are engaged or are likely to be engaged in the industry.

(*b*) To prepare, edit, print, publish, issue, acquire and circulate books, papers, periodicals, gazettes, circulars and other literary undertakings treating of or bearing upon the said trades or industries or any of them and to establish, form and maintain museums, collections, libraries and collections of literature, statistics, scientific data and other information relating to the said trades or industries or any of them or to matters of interest to the Members thereof, and to translate, compile, collect, publish, lend and sell, and endeavour to secure, or contribute to, the translation, compilation, collection and publication, by Parliament, Government Departments and other bodies or persons, of any such literature, statistics and information, and to disseminate the same by means of the reading of papers, delivery of lectures, giving of advice, the appointment of advisory officers or otherwise.

(*c*) To retain or employ skilled, professional or technical advisers or workers in connection with the objects of the Association, and to pay therefor such fees or remuneration as may be thought expedient, also to found, aid, maintain and endow scholarships and bursaries for the remuneration, instruction and support of students in research work, or persons engaged in studying the principles involved in any of the said trades or industries or connected therewith, whether in the laboratories of the Association or elsewhere, and to employ and remunerate as may be expedient, instructors and supervisors for such students and also for persons engaged in studying the principles involved in any of the said trades or industries or connected therewith, paying due regard to the provision of instruction by existing institutions.

(*d*) To encourage the discovery of, and investigate and make known the nature and merits of inventions, improvements, processes, materials and designs which may seem capable of being used by Members of the Association for any of the purposes of the said trades or industries or any of them and to acquire any patents or licenses relating to any such inventions, improvements of processes, and to acquire and register any designs or standardisation marks, whether for general or special purposes, with a view to the use thereof by Members of the Association and others upon such terms as may seem expedient, and to develop, perfect and test the value of such inventions, improvements, processes and designs by manufacturing, exhibiting and placing on the market any article or substances to which the same may be capable of application.

(*e*) To apply to the Government, public bodies, Urban, Local, Municipal, County and other bodies, corporations, companies or persons for, and to accept grants of money and (subject to Section 19 of the Companies (Consolidation) Act, 1908) of land, donations, gifts, subscriptions and other assistance with a view to promoting the objects of the Association, and to discuss and negotiate with the Committee of the Privy Council for Scientific and Industrial Research and other Government Departments, public and other bodies, corporations, companies or persons, schemes of research and other work and matters within the objects of the Association and to conform to any proper conditions upon which such grants and other payments may be made.

(*f*) To establish, promote, coöperate with, become a member of, act as, or appoint trustees, agents or delegates for, control, manage, superintend, afford financial assistance to, or otherwise assist the research work of any associations and institutions and other bodies incorporated or not incorporated, whose objects include scientific or industrial research.

(*g*) To establish, maintain, control and manage branches of the Association in the United Kingdom and elsewhere as may seem expedient, and from time to time to determine the constitution, rights, privileges, obligations and duties of such branches, and, when thought fit, to dissolve and modify the same.

(*h*) To undertake and execute any trusts which may be conducive to any of the objects of the Association.

(*i*) To carry out any of the above-mentioned research or other scientific work, and to do all or any of the above-mentioned things whether affecting the whole of the said trades or industries or merely one or more particular parts or sections of the said trades or industries or any of them or the business of any particular member or group of members of the Association, and, in the case of work not affecting the whole of the said trades or industries, to make such arrangements as to special payment by such particular sections or members or groups of members as may be expedient.

(*j*) To borrow or raise any money that may be required by the Association upon such terms as may be deemed advisable, and in particular by the issue of bonds, debentures, bills of exchange, promissory notes or other obligations or securities of the Association, or by mortgage or charge of all or any part of the property of the Association.

(*k*) To draw, make, accept, indorse, discount, execute and issue promissory notes, bills of exchange and other negotiable or transferable instruments.

(*l*) To invest the moneys of the Association not immediately required in any one or more of the modes of investment for the time being authorised by law for the investment of trust moneys and in such manner as may from time to time be determined.

(*m*) Subject to the provisions of the 19th Section of the Companies (Consolidation) Act, 1908, to purchase, take on lease or in exchange, hire or otherwise acquire any real and personal property, and in particular any land, buildings, workshops, factories, laboratories, machinery, plant, apparatus, appliances and any rights or privileges necessary or convenient for the purposes of the Association, and to construct, erect, alter, improve and maintain any buildings which may be from time to time required for the purposes of the Association, and to manage, develop, sell, demise, let, mortgage, dispose of, turn to account or otherwise deal with all or part of the same with a view to the promotion of the objects of the Association.

(*n*) To pay all expenses, preliminary or incidental to the formation of the Association and its registration.

(*o*) To use the funds of the Association in the employment of persons of

learning or skill, and the provision and use of buildings, and of instruments, materials and appliances, and of any of the equipment of the Association for any form of scientific studies which may be considered to have some bearing, whether immediate or ultimate, on practical problems involved in the nature or use of . . . .

(*p*) To collect, arrange, index and publish information as to materials, patents, processes, machines, appliances and tools used or known in or in regard to . . . . or the said trades or industries or likely to be useful thereto, and to establish and maintain a Bureau of Information for the benefit of members of the Association.

(*q*) To establish and support or aid in the establishment and support of Associations, institutions, funds, trusts and conveniences calculated to benefit employees or ex-employees of the Association or the dependents or connections of such persons, and to grant pensions and allowances to and to make payments towards insurance of such persons.

(*r*) To procure the Association to be registered or recognised in any part of the British Empire or in any foreign country or place.

(*s*) To do all such other lawful things as may be incidental to or conducive to the attainment of the above objects.

Provided always that nothing herein contained shall empower the Association to carry on the business of life assurance, personal accident assurance, fire insurance or employers' liability insurance or the business of insurance within the meaning of the Assurance Companies Act, 1909, Section 1.

Provided also that the Association shall not support with its funds any object, or endeavour to impose on or procure to be observed by its Members or others any regulation, restriction, or condition, which, if an object of the Association, would make it a trade union.

Provided also that in case the Association shall take or hold any property subject to the jurisdiction of the Charity Commissioners or Board of Education for England and Wales, or any authority exercising corresponding jurisdiction outside England and Wales, the Association shall not sell, mortgage, charge or lease the same without such authority, approval or consent as may be required by law, and as regards any such property the Managers or Trustees of the Association shall be chargeable for such property as may come into their hands and shall be answerable and accountable for their own acts, receipts, neglects and defaults, and for the due administration of such property in the same manner and to the same extent as they would as such Managers or Trustees have been if no incorporation had been effected, and the incorporation of the Association shall not diminish or impair any control or authority exerciseable by the Chancery Division, the Charity Commissioners, or the Board of Education or any such other authority as aforesaid over such Managers or Trustees, but they shall, as regards any such property, be subject jointly and separately to such control or authority as if the Association were not incorpo-

rated. In case the Association shall take or hold any property which may be subject to any trusts, the Association shall only deal with the same in such manner as allowed by law having regard to such trusts.

4. The income and property of the Association, whencesoever derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, gift, division, bonus or otherwise howsoever by way of profit, to the Members of the Association.

Provided that nothing herein shall prevent the payment in good faith of reasonable and proper remuneration to any officer or servant of the Association or to any member of the Association, in return for any services actually rendered to the Association, or for any material, labour, plant or power supplied for experimental purposes, nor prevent the payment of interest at a rate not exceeding six per centum per annum on money lent, or payment of a reasonable and proper rent for premises demised or let by any Member of the Association, but so that no member of the Council or Governing Body of the Association shall be appointed to any salaried office of the Association or any office of the Association paid by fees, and that no remuneration or other benefit in money or money's worth shall be given by the Association to any Member of such Council or Governing Body except by way of repayment of out-of-pocket expenses and interest at the rate aforesaid on money lent or the payment of a reasonable and proper rent for premises demised or let to the Association (or any remuneration to any member of the Council in accordance with any recommendation by or with the approval of the Committee of the Privy Council for Scientific and Industrial Research), provided that nothing hereinbefore contained shall prevent any payment to any Railway, Gas, Electric Lighting, Water, Cable or Telephone Company of which a member of the Council may be a member, or to any corporate body of which a member of the Council may be a member or shareholder holding less than one-hundredth part of its capital or to any other corporate body or to any firm with the previous consent of the Committee of the Privy Council for Scientific and Industrial Research, and Members shall not be bound to account for any share of profits they may receive in respect of any such payment.

Provided also that nothing herein shall prevent any Member of the Association, whether a member of the Council or not, from exercising any processes and making, using, acquiring and vending any articles and things in the ordinary course of his business for profit or otherwise under any license or permission in respect of any discovery, invention and patents resulting from the work of the Association.

5. No addition, alteration or amendment shall be made to or in the regulations contained in the Articles of Association for the time being in force, unless the same shall have been previously submitted to and approved by the Board of Trade in consultation with the Committee of the Privy Council for Scientific and Industrial Research.

6. The fourth and fifth paragraphs of this Memorandum contain conditions on which a license is granted by the Board of Trade to the Association in pursuance of Section 20 of the Companies (Consolidation) Act, 1908.

7. The liability of the Members is limited.

8. Every Member of the Association undertakes to contribute to the assets of the Association, in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges and expenses of winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding £5.

9. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other institution or institutions having objects similar to the objects of the Association, and which shall prohibit the distribution of its or their income and property amongst its or their Members to an extent at least as great as is imposed on the Association under or by virtue of Clause 4 hereof, such institution or institutions to be determined by the Members of the Association, subject to the approval of the Committee of the Privy Council for Scientific and Industrial Research at or before the time of dissolution, or in default thereof by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter, and if and so far as effect cannot be given to the aforesaid provision, then to some charitable object.

10. True accounts shall be kept of the sums of money received and expended by the Association, and the matters in respect of which such receipts and expenditure take place, and of the property credits and liabilities of the Association, and, subject to any reasonable restrictions as to the time and manner of inspecting the same that may be imposed in accordance with the regulations of the Association for the time being, shall be open to the inspection of the Members. Once at least in every year the accounts of the Association shall be examined, and the correctness of the balance sheet ascertained by one or more properly qualified auditor or auditors.

Bulletin of the National Research Council

Volume 1

Number 1. The national importance of scientific and industrial research. By George Ellery Hale and others. Price 50 cents.

Number 2. Research laboratories in industrial establishments of the United States of America. Compiled by Alfred D. Flinn. (In preparation.)

Number 3. Periodical bibliographies and abstracts for the scientific and technological journals of the world. Compiled by R. Cobb. (In preparation.)

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Number 5. Some problems of sidereal astronomy. By Henry N. Russell. (In press.) Price 30 cents.

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Vol. 1. Part 2 MARCH, 1920 Number 2

BULLETIN

OF THE

NATIONAL RESEARCH COUNCIL

RESEARCH LABORATORIES IN INDUSTRIAL ESTABLISHMENTS OF THE UNITED STATES OF AMERICA

Compiled by
ALFRED D. FLINN, Secretary, Engineering Foundation,
Assisted by
A. J. PORSKIEVIES, Member American Institute of Electrical Engineers
and
RUTH COBB, National Research Council

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
OF
THE NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D. C.
1920

Announcement Concerning Publications of the National Research Council

The Proceedings of the National Academy of Sciences

has been designated as the official organ of the National Research Council for the publication of accounts of research, committee and other reports, and minutes.

Subscription rate for the "Proceedings" is $5 per year. Business address: Home Secretary, National Academy of Sciences, Smithsonian Institution, Washington, D. C.

The Bulletin of the National Research Council

presents contributions from the National Research Council, other than proceedings, for which hitherto no appropriate agencies of publication have existed.

The "Bulletin" is published at irregular intervals. The subscription price, postpaid, is $5 per volume of approximately 500 pages. Numbers of the "Bulletin" are sold separately at prices based upon the cost of manufacture (for list of bulletins see third cover page).

The Reprint and Circular Series of the National Research Council

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BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

Vol. 1, Part 2 MARCH 1920 Number 2

RESEARCH LABORATORIES IN INDUSTRIAL ESTABLISHMENTS OF THE UNITED STATES OF AMERICA

A CLASSIFIED LIST WITH SOME INFORMATION ABOUT STAFF, WORK AND EQUIPMENT

Compiled by ALFRED D. FLINN, Secretary, Engineering Foundation, Assisted by A. J. PORSKIEVIES, Member, American Institute of Electrical Engineers, and RUTH COBB, National Research Council

CONTENTS

Herein are given the names of approximately three hundred laboratories in industrial establishments in the United States of America, which have stated in direct correspondence that they are engaged in research. Most of them devote but a portion of their effort to research, and a number are probably not research laboratories, under a strict definition of that word. Nevertheless, in this first publication of the lists, all laboratories have been included which have supplied information and which by a liberal interpretation do any research work. The 'Annual Chemical Directory of the United States,' published by Williams and Wilkins Company, Baltimore, Maryland, contains lists of laboratories in five classes: (1) Industrial, (2) Institutional, (3) Federal and State, (4) Municipal, (5) Commercial. This publication does not distinguish between research and other laboratories.

Research is sometimes differentiated into 'scientific' and 'industrial.' Scientific research comprises investigations directed toward the discovery of new truths for the sake of increasing human knowledge. Industrial research is the endeavor to learn how to apply scientific facts to the ser-

vice of mankind. Many laboratories are engaged in both industrial research and industrial development. These two classes of investigation commonly merge so that no sharp boundary can be traced between them. Indeed, the term research is frequently applied to work which is nothing else than development of industrial processes, methods, equipment, production or by-products. For development, apparatus is often used of larger size than is common in physical and chemical laboratories; it is frequently of semi-commercial scale or even of full manufacturing size. Furthermore, in practice it frequently is difficult to keep clear the distinction between scientific and industrial research.

All information given was obtained directly by correspondence. By using second-hand information and published articles, the list of laboratories could have been extended somewhat. It was preferable that only original and unquestionably authentic statements should be used in the *Bulletin of the National Research Council.* Insofar as has been possible the phraseology of the original correspondence has been used.

No investigation has been made to ascertain the character of any laboratory listed, nor the quality of work done Statements are based upon letters or other information supplied by the laboratories at first hand. Consequently, the compiler has accepted these statements, but does not vouch for their accuracy. He may have fallen into errors in extracting and interpreting the letters. Some laboratories gave full information; others meager. An endeavor has been made, especially in the latter cases, to utilize all the information that could be extracted from the letters.

Corrections and more information will be welcomed so that a succeeding edition of this bulletin may be better. For this purpose a special blank is provided. In case of error or omissions in any of the data given, the corresponding item should be filled in and the sheet returned to the Publication Office, National Research Council, 1201 Sixteenth St., Washington, D. C. Return sheets giving information concerning industrial research laboratories which are not included in this list will also be welcomed.

LIMITATIONS OF THE LIST

Laboratories connected with federal, state or municipal governments or with educational institutions were from the outset excluded from the inquiry as being in other fields, although frequently engaged upon investigations closely related to industrial research. The concerns which are not actually supporting laboratories in their own works have not been included, nor have the associations maintaining fellowships in certain educational institutions. They are to be encouraged, but this compilation is limited to the laboratories themselves, rather than organizations

supporting research. In tentative form the list of industrial research laboratories, containing then 350 names, was presented to the June, 1918, meeting of the American Society for Testing Materials, as a step in the process of gathering the information sought. This tentative list was obtained chiefly by letters to a few men having some knowledge of research in industry. Although incomplete, it has been useful in several ways besides aiding in the preparation of the list as now published. In search of information, letters were sent to 1350 establishments reported to have laboratories, asking for brief general statements, in the following form:

Staff (name of person in charge of research work; classes such as chemists, physicists, engineers, assistants; number of each).

Research Time (all, half, one-third, or other approximation).

Research Work (general kinds, with reference, if permissible, to special problems which would indicate the scope of the work which the laboratory can undertake). And—

Equipment (not a detailed list, but a summary indicating kinds and capacities in a general way and mentioning apparatus of unusual character or size).

Approximately 500 replies were received; 38 companies stated that they had no laboratories; 153 others that their laboratories did no real research; from the remaining replies, the alphabetical and classified lists have been compiled. Other companies are believed to have laboratories which should be in this list, but detailed information has not yet been received from them.

Knowing that some elaborate endeavors to collect information in this and other fields had fallen under their own weight, the present compiler decided to be content, in this first venture, with such data as could be readily obtained. It was believed that if these imperfect results demonstrated a need for better, cooperation in perfecting the compilation could be had subsequently. Furthermore, progress in industrial research would make another edition necessary in a relatively short time. In preparing this later edition, benefits would doubtless be received from the interest aroused in the subject by this first printing and from the experience gained.

Throughout the lists, an endeavor has been made to print each name exactly in the style used on the company's stationery, giving heed to spelling and abbreviations.

SYSTEMS OF CLASSIFICATION

For convenience of reference, the list of laboratories is given in four arrangements: 1. Alphabetical by the names of the companies. 2. Geographical by states. 3. A scientific and engineering classification, in

accordance with the nature of the work done or the general character of the industries. 4. A commercial classification, using trade designations in common use.

The alphabetical list carries all the information; the others, the names only. For the third list, no classification was found, and therefore one was devised with the assistance of members of the National Research Council, of the Engineering Foundation, and other persons interested in research work. It is based in part upon the classifications used for *Chemical Abstracts* and *Science Abstracts*. Likewise for the fourth list no suitable classification was ready to hand. Those of the United States Census, a few of the States, and some trade directories, were examined. These two classifications are printed separately from the list of laboratories, for convenience of reference or for other use.

In the Scientific and Engineering Classification, an attempt has been made to classify the laboratories, at least partially, from the view points of the research man, the scientist and the engineer. The Commercial Classification follows lines familiar to the manufacturer and the business man. In some cases the information obtained was so meager that classification was difficult or almost impossible. Corrections in these classification lists may also be made on the special blank provided, and will be welcomed for use in a succeeding edition.

Alphabetical List of Laboratories Connected with Industrial Establishments, giving the Name of the Director of Research and Some Information about Staff, Research Work and Equipment

1. **Abbé Engineering Company,** 220 Broadway, New York, N. Y. Laboratory at 230 Java St., Brooklyn, N. Y. Designs pulverizing and grinding machinery.

Research staff: H. F. Kleinfeldt and 2 men experienced in machinery.

Research work: Part time of 3 on the solution of problems which involve crushing, grinding, pulverizing, mixing, and sifting machinery.

Unusual equipment: Ball mills, pebble mills, rotary cutters, disintegrators, crushers, mixers, and sifters.

2. **Acheson Graphite Company,** Niagara Falls, N. Y. Manufactures graphite products, including dry-cell filler, paint pigment, stove polish, pencils, electrodes, crucibles, tubes, muffles, graphite and grease lubricants.

Research staff: A. M. Williamson and 5 or 6 chemists.

Research work: One-third time of 6, largely on a commercial scale, chemists being in charge of the manufacturing processes. Building and organization of a special laboratory for research in process.

3. **Aetna Explosives Company, Inc.,** 120 Broadway, New York, N. Y. Laboratory at Emporium, Pa.

Research staff: Fred Olsen and 1 assistant chief chemist, 8 assistant chemists, 2 laboratory assistants, 1 stenographer.

Research work: Full time of 13 on general research and on methods of manufacture of mineral acids and military and domestic explosives.

Unusual equipment: Semi-commercial scale apparatus for nitration; special equipment for analysis of explosives and for explosive testing.

4. **Aluminum Castings Co., The,** Cleveland, Ohio. Makes aluminum, brass and bronze castings.

Research staff: Zay Jeffries, 1 organizing engineer, about 10 chemists, 10 engineers, 1 specialist each in metallography, motor-testing and physical testing; necessary assistants.

Research work: Large part time of 40 to 50 on new alloys, especially aluminum, and aluminum bronze and brass; special casting processes and study of characteristics of products produced by them.

Unusual equipment: Internal combustion motor laboratory well equipped. Prepared to test apparatus requiring accurate energy measurements, such as gears. Dynamometers of 400, 200 and 150 horsepower; 50,000- and 10,000-pound tensile testing machines, Brinell hardness machine, White-Souther fatigue testing machine; special machine for testing bearings, Erickson cup testing machine; Cambridge Instrument Company impact testing machine; apparatus for determination of thermo-critical points, photo-micrographic outfit; apparatus for coefficients of thermal expansion and heat conductivity; small electric furnaces, up to 1800 degrees C.

5. **American Agricultural Chemical Company, The.** Agricultural Service Bureau, 92 State St., Boston, Mass. Chemical laboratory at Carteret, N. J.

Research staff: H. J. Wheeler, 9 agronomists and chemists, superintendent of experiment farm, 2 expert photographers and a clerical staff.

Research work: Study of requirements of soils where fertilizers have not been used; study of citrus fruits and other crops in Florida in connection with unusual types of soil; experiments with fertilizers in Wisconsin and Minnesota.

6. **American Beet Sugar Company,** Oxnard, Cal.

Research staff: H. E. Zitkowski and 2 agriculturists, 4 chemists and 2 engineers.

Research work: One-half time of 9 on agricultural problems of crop production, seed treatment to increase vitality, rotation, fertilization, etc.; increase of efficiency of processes, to reduce sugar losses, improve quality of product, develop by-products; recovery of nitrogen and potash.

Unusual equipment: Diffusion battery of 24 one cubic foot capacity cells; Steffens molasses desugarizing plant, capacity 100 to 200 pounds molasses per hour, with mill, cooler, filtering apparatus, refrigerating machine, and experimental lime kiln; Dorr thickener, 14 feet diameter, 8 feet high, two compartments together with 4- x 2-foot Oliver continuous filters, for increasing filtration efficiency; experimental retort for destructive distillation of liquids, such as Steffens waste waters, with object of devising methods for recovery of nitrogen and potash (can handle 200 pounds waste water with a 50 percent solid content per hour).

7. **American Brass Company, The,** Waterbury, Conn. Chemical, metallographic and metallurgical laboratory at Waterbury; physical and electrical testing laboratory at Ansonia.

Research staff: William H. Bassett and 3 metallurgists, 2 chemists, 1 physicist and metallographer, 1 metallographer, 2 metallurgical engineers, 1 testing engineer and necessary assistants.

Research work: One-third time of 11 on nature and effect of impurities in copper and its alloys; effects of mechanical working, heat treatment, corrosion and conditions of exposure.

Unusual equipment: Waterbury laboratory equipped for inorganic chemical analysis and assaying; metallographic equipment includes electrical furnaces and pyrometric apparatus for study of heat treatment of non-ferrous metals and alloys; Adam Hilger, Quartz "D" spectroscope of high sensitiveness; facilities for production of special alloys, corrosion and other special tests. At Ansonia are 200,000-pound Olsen, 100,000-pound Riehle and smaller testing machines, covering physical testing of all materials down to very fine wire; fatigue and friction testing apparatus; electrical apparatus for accurate resistance and conductivity tests.

8. **American Can Company,** 120 Broadway, New York, N. Y. Laboratory at 447 West 14th St., New York, N. Y.

Research staff: Wm. S. Sellars and 1 assistant chemist, 2 analytical and research chemists, 1 analyst and laboratory assistant and 1 laboratory assistant.

Research work: One-half time of 6 on co-operative work with packers of food products in investigating chemical changes taking place in food

products and their influence upon the preservation of the food, its quality, and its wholesomeness. Manufacturing operations, including study of fluxes, white metal alloys, coals, oils and other materials.

Unusual equipment: Carbon dioxide expansion apparatus, permitting solution for volumetric analyses in the absence of oxygen. McIntosh photo-micrographic apparatus; special vulcanizing equipment, grinding and polishing apparatus; special apparatus for analysis of tin plate and solder for tin content; apparatus for investigating tin cans and sealing them; can testers; vacuum pumps; vacuum pots; incubators.

9. **American Cotton Oil and Associated Cos.,** 65 Broadway, New York, N. Y. Research Department, 225 W. 18th St., Chicago, Ill.

Research staff: V. H. Gottschalk, 4 senior chemists, 3 junior chemists, 2 chemical engineers and 2 helpers.

Research work: Full time of 11, and one-half time of 1, on theoretical and industrial applications in connection with vegetable oils, their manufactured products, and soaps.

Unusual equipment: Miniature plant for experimental work on treating oils and fats.

10. **American Cyanamid Company,** 511 Fifth Avenue, New York, N. Y. Has three plants and a laboratory at each but research and development work are being centralized at plant nearest New York.

Research staff: W. S. Landis, 3 skilled chemists and several assistants, as a minimum. Usually includes 10 or 15 skilled men being trained for operating positions in new processes.

Research work: Full time of staff on fertilizers, nitrogen fixation, phosphates, potash, ammonia compounds and derivatives. Much of the work done in the experimental plants and laboratories is development, rather than true research.

Unusual equipment: Apparatus is of commercial size; frequently a complete small commercial plant is leased for experimental work. Laboratory equipment is provided anew for each large scale investigation.

11. **American Leather Research Laboratory,** 80 South St., New York, N. Y.

Research staff: George L. Terrasse, 1 chemist, 1 assistant and 1 stenographer.

Research work: Full time of 4 on problems connected with leather manufacture.

12. **American Optical Company,** Southbridge, Mass.

Research staff: C. H. Kerr, 2 physicists, 1 astronomer, 1 general chemist, 1 physical chemist, and 5 assistants.

Research work: Full time of 11 on metallurgical research in non-ferrous metals, especially on ability of metal and alloys to stand repeated workings. Spectral transmission of glasses, for example, glasses to reflect or absorb infra red. Optical designing in general, especially designing of scientifically correct ophthalmic lenses; also optical instrument designing. Abrasive material for grinding and polishing glass. Fusing together glasses of different types. Adhesives. Glass strength investigations.

Unusual equipment: Optical measuring apparatus for transmission in the ultra-violet, visible and infra red; Zeiss metallographic outfit; strength of materials testing apparatus.

13. **American Radio and Research Corporation,** Medford, Mass.

Research staff: V. Bush, 1 engineer manager and 5 assistants.

Research work: Full time of 7 on phenomena at radio frequencies, and other matters intimately connected with radio telegraphy and telephony.

Unusual equipment: Apparatus for measurements and research at high frequency, such as arcs, oscillating bulbs, generators and bridges.

14. **American Research Fund,** Atlanta, Ga.

Research staff: E. S. Rankin and 1 analytical chemist.

Research work: Full time of 2 on study of reduction of alcohol in medicinal extracts and preserving fluids.

15. **American Rolling Mill Co., The,** Middletown, Ohio. Specializes in commercially pure iron and sheets for electrical purposes.

Research staff: W. J. Beck, 1 chief chemist, 1 electrical engineer, 2 chemists, 1 metallurgist and necessary assistants.

Research work: Full time of 6 on metallurgical problems, corrosion of iron and steel, physical properties, heat treating of soft steels, etc. Some of the work is development rather than true research.

Unusual equipment: Metallurgical apparatus. Equipment for all chemical analyses in connection with steel plants, including hydrogen, oxygen and nitrogen gases.

16. **American Sheet and Tin Plate Co.,** 210 Semple St., Pittsburgh, Pa.

Research staff: R. E. Zimmerman, 9 chemical engineers, 2 chemists, 1 physicist, 1 metallurgist.

Research work: Full time of 14 on chemical engineering problems relating to the manufacture of sheet steel, tin plate, and galvanized sheets; metallurgy, metallography and pyrometry as applied to these manufacturing processes.

17. **American Sugar Refining Company, The,** 117 Wall St., New York, N. Y. Service Division.

Research staff: A. V. Fuller, 2 chemists and 1 assistant.

Research work: One-half time of 4 on adaptability of various sugar cane products to special purposes; causes of failure in manufacture of sugar products and their remedies, and development of new sugar food products.

Unusual equipment: A trade candy kitchen in conjunction with the laboratory.

American Synthetic Dyes, Inc. See Butterworth-Judson Corporation.

18. **American Vanadium Company,** Bridgeville, Pa.

Research staff: B. D. Saklatwalla, 1 electrochemist, 1 metallurgical engineer, 1 metallographer and necessary assistants.

Research work: Three-fourths time of 4 on development of vanadium steels, other alloy steels, vanadium alloys, and new processes for extraction of vanadium from different minerals.

Unusual equipment: Physical testing, chemical, electrochemical and metallographic apparatus.

19. **American Window Glass Co.,** Factory No. 1, Arnold, Pa.
Research staff: L. P. Forman, 4 chemists and 2 ceramists.
Research work: One-third time of 7 on new developments in glass industry, and ceramic work.
Unusual equipment: Pyrometric apparatus; high and low temperature electric furnaces.

20. **American Writing Paper Co.,** Holyoke, Mass. Chemical research laboratory.
Research staff: R. E. Rindfusz and 7 chemists.
Research work: Full time of 8 on testing new fibers to determine possible commercial value; special paper problems.
Unusual equipment: 2 small model heaters, 3 small model boilers, a machine for testing tub sizing materials to determine their value in paper-making. 66-inch combination Fourdrinier and cylinder paper machine with full equipment for experimental purposes only.

21. **American Zinc, Lead and Smelting Company,** 3759 West Pine Boulevard, St. Louis, Mo.
Research staff: Edward Schramm, 1 analytical chemist, 1 physical chemist, 1 mechanic and laboratory assistant.
Research work: Full time of 4 on conditions for roasting zinc ores, condensation of zinc, fundamental reactions in zinc smelting, methods for determining cadmium in brass.
Unusual equipment: High temperature furnaces.

22. **Amoskeag Manufacturing Company,** Manchester, N. H. Textile mills.
Research staff: William K. Robbins, 3 chemists and 1 laboratory helper.
Research work: Small part time of 4 on waste recovery, dye, bleaching, sizing and testing problems. Semi-commercial scale experiments in plant.
Unusual equipment: Steam bath for dye tests, exposure boards for light and weather tests, cloth and yarn breaking machines.

23. **Anaconda Copper Mining Co.,** Anaconda, Mont.
Research staff: F. F. Frick, 9 assistants and 10 to 20 non-technical assistants.
Research work: Full time of 20 to 30 on problems connected with the industry.

24. **Ansco Company,** Binghamton, N. Y. Manufactures photographic equipment and supplies.
Research staff: Alfred B. Hitchins and 5 trained men.
Research work: Full time of 6 on photographic work.
Unusual equipment: For photographic emulsions, spectroscopic work, spectro-photography, photometry and photo-micrography, testing of dyes and color filters, polariscopic and refractometric work; high temperature ovens. Experimental laboratory for motion picture work.

25. **Arbuckle Brothers,** Old Slip & Water St., P. O. Box 780, New York, N. Y. Sugar refiners, and manufacturers of flavoring extracts and spices.
Research staff: A. Hugh Bryan.
Research work: Small part of time on problems connected with the industry.

26. **Arlington Mills,** Lawrence, Mass. Textile mills.

Research staff: R. P. Iddings, 3 chemists and 3 assistants.

Research work: Full time of 1 on problems in manufacture of textiles.

27. **Armour Glue Works,** 31st Place & Benson St., Chicago, Ill. Laboratory serves also Armour Soap Works, Armour Ammonia Works, Armour Curled Hair Works, and Armour Sandpaper Works.

Research staff: J. R. Powell, 6 chemists, 6 laboratory assistants and 4 helpers.

Research work: Full time of 1 and part time of 2 on investigation of some of the plant processes. Work is principally analytical, for plant control.

28. **Art in Buttons,** Incorporated, Rochester, N. Y.

Research staff: F. W. Ross and 10 assistants.

Research work: Full time of 11 on problems concerning particular kind of button manufacture.

Unusual equipment: Temperature humidity controlled room; apparatus for strength of materials, elasticity, hardness, density and viscosity. Experimental machine shop for developing machinery peculiar to button manufacture.

29. **Associated Factory Mutual Fire Insurance Companies,** Inspection Department, 31 Milk St., Boston, Mass.

Research staff: Edw. A. Barrier, 2 chemists and 5 to 7 engineers.

Research work: One-sixth to one-fourth time of 9 on fire-protection engineering problems.

Unusual equipment: Apparatus for chemical, hydraulic and mechanical tests and investigations of fire-protection devices.

30. **Atlantic Refining Company, The,** 3144 Passyunk Avenue, Philadelphia, Pa. Manufactures petroleum products.

Research staff: T. G. Delbridge, 5 chemical engineers, 9 chemists, 1 physicist and 18 assistants. Mechanical and electrical engineering staffs collaborate with laboratory.

Research work: Three-fourths time of 34 on manufacturing methods of petroleum refinery, including study of manufacturing equipment and of equipment for testing.

Unusual equipment: A laboratory-scale petroleum refinery, together with complete equipment for study of petroleum products; large-scale manufacturing apparatus in the plant is at disposal of laboratory staff.

31. **Atlas Powder Co.,** Wilmington, Del. Manufactures explosives; maintains three laboratories for research.

Research staff: M. C. Burt, Reynolds, Pa.; G. C. Given, Stamford, Conn.; F. Bonnet, Jr., Landing, N. J., and 35 chemists.

Research work: Full time of 38 on explosives of all kinds, caps, electric detonators, leather cloth, lacquers and miscellaneous chemicals.

Unusual equipment: Designed for experimental work on explosives, miscellaneous chemicals, leather cloth and lacquers.

32. **Ault & Wiborg Company, The,** Cincinnati, Ohio. Manufactures lithographic and printing inks, varnishes, litho stones, bronze powders, dry colors, acids, typewriter ribbons, carbon paper.

Research staff: A. B. Davis and 10 to 15 research chemists.

Research work: Full time of 11 to 16 on problems connected with dyestuffs and intermediates.

Unusual equipment: Especially for dyestuffs; technical laboratory for developing finished researches on a factory scale.

33. **Babcock Testing Laboratory,** 801 Ridge Road, Lackawanna, N. Y.

Research staff: Stephen C. Babcock, 2 chemists, 1 engineer and helpers.

Research work: Three-fourths time of 4 on milk pasteurization in original packages, sanitation, corrosion, destructive distillation of waste products to recover acetone, etc. Paint driers, varnish driers, glass, plastics.

Unusual equipment: Special apparatus for destructive distillation.

34. **Babcock & Wilcox Co., The,** Bayonne, N. J. Manufactures steam boilers.

Research staff: E. G. Bashore and 6 men.

Research work: Full time of 2 and part time of 4 on development of refractory materials, embrittlement of steel, aluminum coating on steel, betterment of boiler practice.

Unusual equipment: Special Bureau of Mines bomb cast from Illium metal. Spectroscopic apparatus; instruments for electrical measurements; viscosity and surface tension apparatus. Furnaces and apparatus for pyrometer and thermometer calibration. Two complete micrographic outfits. 150,000-pound Riehle testing machine, Upton-Lewis torsional and alternate bending machine, Brinell machine, scleroscope. Special equipment for refractories research. Special equipment for investigation of hydrogen embrittlement in steel.

35. **Baker, J. T., Chemical Co.,** Phillipsburg, N. J.

Research staff: Wm. P. Fitzgerald and 3 assistants.

Research work: Full time of 1 on methods of testing reagents, methods of manufacture, etc.

36. **Baldwin Locomotive Works, The,** Philadelphia, Pa.

Research staff: H. V. Wille, 2 chemists and 7 assistants.

Research work: Small part time of 10 on problems connected with the plant.

Unusual equipment: 4 Olsen testing machines up to 600,000 pounds capacity; Brinell machines and scleroscope. Equipment necessary for determining elements in iron, steel, bearing metals and alloys.

37. **Barrett Company, The,** 17 Battery Place, New York, N. Y. Manufactures coal tar products. Research Laboratory Department at New York, Chemical Department at Frankford, Philadelphia, Pa. A works laboratory at each plant.

Research staff (*N. Y. laboratory*): C. R. Downs, 35 chemists and chemists' assistants; and 15 other men. Special Products Department, under direct control of Research Department, employs 60 mechanics and process men.

Research work: Full time of 50 on problems in connection with improvement of products or processes, and development of new uses for normal products. General Manufacturing Department undertakes many experimental engineering problems, for which Research Department acts in consulting capacity.

Unusual equipment: Research laboratory occupies 4000 square feet; adjoining is a 40- x 50-foot building for experimental plant operations.

Research staff (*Frankford laboratory*): F. H. Rhodes and 15 chemists.

Research work: Full time of 16 on problems related to processes for new products; improvement of efficiency of present processes, and development of by-products; entirely in connection with own plant.

Unusual equipment: A few pieces of semi-works scale apparatus, such as agitators, vacuum driers, presses.

38. **Bausch & Lomb Optical Co.,** Rochester, N. Y.

Research staff: Hermann Kellner, physical laboratory and optical glass plant, with 8 senior members, 4 junior members, 4 laboratory assistants and 3 technical assistants; Frank P. Kolb, chemical laboratory, 3 chemists and 2 assistants.

Research work: One-half time of 28 on optics and glass making, emery and rouge washing and grading, grinding and polishing experiments, cements, fillers, glass washing, glass silvering, metal plating.

39. **Beaver Company, The,** Buffalo, N. Y. Manufactures Beaver Board and other wallboards for buildings.

Research staff: B. W. Sidwell and 6 assistants.

Research work: Full time of 7 on pulp and paper problems, especially manufacturing and technical difficulties of wallboard production.

Beaver Valley Glass Company. See H. C. Fry Glass Company.

40. **Beckman and Linden Engineering Corporation,** Balboa Building, San Francisco, Cal.

Research staff: J. W. Beckman, H. E. Linden, and a varying number of chemists, physicists and assistants.

Research work: Full time of staff on chemical, electrochemical and organic problems; salts occurring in natural brines; chemistry of barium and strontium salts; electrolytic manufacture of metallic magnesium directly from its oxides; cracking of oils by high-tension discharges.

Unusual equipment: Large motor-generator set for direct-current electrolysis and transformers for high-tension work.

41. **Belden Manufacturing Company,** 23rd St. & Western Ave., Chicago, Ill. Manufactures rubber insulated wires and cables, coil-winding machines, electromagnets and similar products.

Research staff: J. V. Van Buskirk.

Research work: Problems relating to own industry.

42. **Bennetts' Chemical Laboratory,** 1142 Market St., Tacoma, Wash. Analytical and consulting chemists, assayers and metallurgists.

Research staff: B. H. Bennetts, 4 chemists and 1 metallurgist.

Research work: Part time of 6 on concentration of manganese ores of Pacific Coast. Atomizing of copper, zinc and aluminum. Agricultural chemistry.

Unusual equipment: Metal atomizing plant for copper, zinc and aluminum.

Benzol Products Co. See National Aniline & Chemical Company.

43. **Berry Bros., Inc.,** Detroit, Mich.

Research staff: Chas. T. Ellis and 3 chemists.

Research work: One-third time of 4 on paint vehicles, varnishes and shellacs.

44. **Bethlehem Shipbuilding Corporation, Ltd.,** Union Plant, San Francisco, Cal.

Research staff: Bryant S. Drake and 4 assistant chemists.

Research work: Small part time of 5 on corrosion of boiler tubes in marine engineering; improvement of strength and homogeneity of non-ferrous alloys.

Unusual equipment: Electric furnace, gas calorimeter, low voltage generator, Olsen automatic and autographic universal testing machine of 200,000 pounds capacity; Shore scleroscope, Brinell hardness apparatus.

45. **Bloede, Victor G., Co.,** Station D, Baltimore, Md. Manufacturing chemists; specialties, dyes, colors, gums.

Research staff: Victor G. Bloede, 1 chemist and 1 assistant chemist.

Research work: Full time of 1 and part time of 2 on starch modification, dextrinization and hydrolization.

Unusual equipment: Dextrinizers, mixing and bolting machines.

46. **Boonton Rubber Manufacturing Company,** Boonton, N. J. Makes electrical insulation and molded products.

Research staff: Geo. K. Scribner, 1 chemist, 1 electrical engineer and 1 mechanical engineer.

Research work: One-third time of 4 on such problems as non-carbonizing molded insulation for high-tension automobile ignition apparatus; synthetic resins.

Unusual equipment: 100,000-volt testing transformer; special apparatus for coating paper and fabric with resins in solution.

47. **Boston Bio-Chemical Laboratory, (Inc.), The,** 585 Boylston St., Boston, Mass.

Research staff: S. C. Prescott, 7 chemists, 1 bacteriologist and assistants.

Research work: Part time of 9 on agricultural problems, especially milk and food.

Unusual equipment: Van Slyke machine for amino nitrogen determination; immersion refractometer.

48. **Brach, E. J., and Sons,** 208 East Illinois St., Chicago, Ill. Manufactures candies. Has a small laboratory for control and research and a manufacturing laboratory.

Research staff: C. O. Dicken and 3 chemists.

Research work: One-third time of 4 on improvement of analytical methods and problems in manufacture of candy.

49. **Bridgeport Brass Company,** Bridgeport, Conn.

Research staff: Charles Ferry, 4 chemists, 1 mechanical engineer, 3 metallographists and 8 assistants.

Research work: One-third time of 17 on general problems incidental to manufacture and fabrication of a large variety of alloys.

Unusual equipment: Facilities for testing non-ferrous alloys, both chemically and physically. Metallographical laboratory for research.

50. **Brown Company** (formerly Berlin Mills Company), Berlin, N. H. Manufactures paper, sulphite, fiber and lumber.

Research staff: Hugh K. Moore and 21 chemical engineers; 17 works chemists in laboratories connected with the mills.

Research work: Full time of 22 on determination of chemical and physical factors which affect hydrogenation of oils; methods of manufacturing carbon tetrachloride, and determination of optimum conditions for method chosen; hydrolysis of wood-waste and fermentation of resulting liquors; uses for 'sulphite-pitch,' especially as a briquette-binder; machine for testing all classes of lubricating oils under any desired condition; conditions for commercial production of acetic anhydride; conditions for production of oxalic acid from wood-waste; structure and methods of impregnation of fiber tubes; commercial development of process for manufacturing carbon bisulphide and sulphur chloride; process for improving cooking acid for sulphite-fiber mill; methods of preparing acetylene tetrachloride; certain procedures in oil-analysis; improved method of preparing bleach powder; reduction of sizing-process in paper mill to an exact procedure; process for preparing monochlorbenzol.

Unusual equipment: New research laboratories nearing completion consist of four floors, having an area of over 11,000 sq. ft. and providing for bureau of tests, physical and chemical laboratories, large scale work, development section, microscopic work and general industrial photography. Laboratories equipped with jacketed kettles, tubular condensers, vacuum pumps, lummus continuous fractionating still, Bristol pyrometer, Sharples laboratory super-centrifuge, Andiffren-Singrun refrigerating machine, quartz mercury-vapor lamp, Sperry laboratory filter press, Schaum and Uhlinger centrifugal-machine. Lovibond tintometer, Greiner colorimeter, spectroscope, pressure-sterilizer, Stormer viscosimeter. In storehouse a large electric-furnace transformer and switchboard, lubricating-oil tester, high-pressure gas compressor, various pieces of quartz apparatus.

51. **Brown & Sharpe Mfg. Co.,** Providence, R. I. Manufactures machinery and tools.

Research work: On gray iron.

52. **Brunswick-Balke-Collender Co., The,** Muskegon, Mich.

Research staff: A. Brill and 3 men.

Research work: One-fourth time of 4 on rubber, glue and wood-working.

53. **Buckeye Clay Pot Co.,** Bassett and Ontario Sts., Toledo, Ohio. Manufactures fire-clay products.

Research staff: Arthur F. Gorton.

Research work: Two-thirds time of 1 on tests of clay including determinations of dry transverse strength, water of plasticity, linear drying shrinkage, screen analysis for fineness, etc., also melting point, ability to withstand load at high temperatures, porosity, linear burning shrinkages, burned strength, and other properties of burned clay.

Unusual equipment: For making both routine and special tests of clays.

54. **Buffalo Foundry and Machine Co.,** 1543 Fillmore Ave., Buffalo, N. Y. Makes vacuum dryers, evaporators and industrial chemical apparatus.

Research staff: Willard Rother, Metallurgical and Physical Testing Department; D. J. Van Marle, Organic Chemical Department;

Charles Lavett, Vacuum Laboratory and Testing Departments; 2 assistant chemists and 5 assistant engineers and operators.

Research work: Small part time of 10 on practical experiments on materials furnished by customers to determine in advance what can be done by means of certain apparatus.

Unusual equipment: Completely equipped metallurgical, chemical and testing laboratories.

55. **Burdett Manufacturing Company,** St. Johns Court at Fulton Street, Chicago, Ill. Makes oxygen and hydrogen gas generating apparatus.

Research staff: E. G. Luening, 1 chemist and 1 assistant chemist.

Research work: Full time of 1, part time of 2 on rates of diffusion of gases, explosive limits of gases, effect of electrolytic action incident to decomposition of water on various materials used in construction (steel, rubber and asbestos) development of special compounds for permanent resistance to such action and to action of comparatively strong alkaline solutions.

Unusual equipment: Equipment for analysis of gases is complete.

Burke Tannery. See Kistler, Lesh & Company.

56. **Butterworth-Judson Corporation,** Newark, N. J. Successor to American Synthetic Dyes, Inc.

Research staff: N. F. Borg, 7 chemists, 2 assistant chemists and 1 helper.

Research work: Full time of 11 on problems relating to dye manufacture.

Unusual equipment: Equipment particularly adapted for work on intermediates, dyes, acids and heavy chemicals, including semi-commercial scale apparatus.

57. **Byers, A. M., Company,** Pittsburgh, Pa. Manufactures wrought iron pipe, oil well tubing and casing.

Research staff: James Aston, several metallurgists and chemists, and assistants.

Research work: One-half time of staff on corrosion and protective coatings of iron; development of wrought iron.

Unusual equipment: For chemical analyses and microscopic examinations of iron and steel; apparatus for corrosion tests and for determining physical characteristics.

By-Products Coke Corporation, See Semet-Solvay Company.

58. **Cabot, Samuel, Inc.,** 141 Milk St., Boston, Mass.

Research staff: Samuel Cabot and 1 assistant.

Research work: One-third time of 2 on coal tar distillates, disinfectants, paints, stains, varnishes.

59. **Carborundum Company, The,** Niagara Falls, N. Y. Manufactures abrasive materials.

Research staff: O. Hutchins, 1 ceramist, 1 organic chemist (glue, rubber, shellac), 15 chemical engineers, 7 assistants with technical experience and 4 non-technical helpers.

Research work: Full time of 29 on ceramic and general technical problems, particularly those of purely scientific nature. Development of new products and improvement on present electric furnace processes. In furnace laboratory are undertaken problems of semi-commercial nature on fairly large scale; investigations on refractories, study of

electric furnace operation and manufacture of some electric furnace products.

Unusual equipment: Microscopic and photo-micrographic outfits. A number of small electric furnaces, an Arsem vacuum furnace, an arc and resistance furnace, several small gas furnaces. Three laboratories and much experimental work in plant.

60. **Carnegie Steel Company,** 1054 Frick Annex Building, Pittsburgh, Pa. Central Research Bureau for United States Steel Corporation.

Research staff: J. S. Unger; chemists, physicists, engineers and assistants selected from works staffs as needed.

Research work: At steel plants, covering problems of steel manufacture, properties of refractories and other materials used in steel manufacture, by-products and the testing of finished products, particularly service tests.

61. **Carus Chemical Company,** La Salle, Ill. Manufactures permanganate of potash, recovered manganese, saccharine.

Research staff: Leslie G. Graper and 5 men.

Research work: Three-fourths time of 6 on development of process for producing calcium and zinc permanganates, chlorsulphonic acid, methyl and ethyl sulphate, saccharine; work on guaiacol.

62. **Case Research Laboratory,** Auburn, N. Y.

Research staff: Theodore W. Case, 3 technical men and several assistants.

Research work: Full time of at least 4 on problems in light and photoelectricity.

Unusual equipment: Apparatus for photo-electric work.

63. **Central Scientific Company,** 460 East Ohio St., Chicago, Ill. Manufactures physical, chemical, agricultural and biological apparatus.

Research staff: Capt. de Khotinsky and 1 assistant.

Research work: Large part time of 2 on development and improvement of apparatus manufactured.

Unusual equipment: For electrical testing.

64. **Champion Ignition Co.,** Flint, Mich.

Research staff: T. G. McDougal and 2 ceramic engineers.

Research work: Three-fourths time of 3 on perfection of high temperature insulation (electrical); super-refractory furnace linings for own use; continuous high temperature factory processes.

Unusual equipment: Laboratory and factory facilities for operations up to 1800 degrees C. Equipment for measuring electrical leakage up to 900 degrees C.

65. **Chandler Engineering Corporation,** 74 Ashland Place, Brooklyn, N. Y. Designs and builds special machinery.

Research staff: Edw. F. Chandler and a number of experts.

Research work: Engineering in connection with special machinery, mechanical, electrical, chemical, aeronautical, marine and ordnance.

Unusual equipment: Chemical and physical laboratories and experimental machine shops, well equipped for scientific investigation.

66. **Charlotte Chemical Laboratories, Inc.,** 606 Trust Building, Charlotte, N. C.

Research staff: F. J. Bartholomew, 2 chemists, 3 chemical engineers, 1 mechanic and 1 laborer.

Research work: Two-thirds time of 8 on development of plant processes; electro-metallurgy of rare elements.

Unusual equipment: Electric vacuum furnaces. Large capacity grinding units.

67. **Chase Metal Works,** Waterbury, Conn. Manufactures copper, brass and other non-ferrous metals.

Research staff: C. H. Stokesbury, 5 chemists, 4 engineers and about 35 assistants.

Research work: Full time of 2 on investigations of properties of brass and copper.

Unusual equipment: Complete chemical equipment for brass mill laboratory; physical laboratory equipment, 100,000-pound Olsen testing machine, 50,000-pound Riehle testing machine, 10,000 — 1,000-pound Olsen wire testing machine, Brinell machine, Spring tester, scleroscopes; metallographic equipment, electric annealing muffles with electrically controlled thermostats.

68. **Cleveland Testing Laboratory Co., The,** 511 Superior Building, Cleveland, Ohio.

Research staff: C. A. Black, 2 chemists and assistants as required.

Research work: One-third time of 3 on problems in connection with industrial plants.

Unusual equipment: Apparatus for steel metallurgical work and for food work.

69. **Columbia Graphophone Manufacturing Company,** Bridgeport, Conn. A laboratory also in New York.

Research staff: Dr. de Stubner.

Research work: Part time of 1 on semi-plastics in connection with record manufacture.

70. **Commonwealth Edison Company,** 120 West Adams St., Chicago, Ill. Operator of large electric light and power generating and distributing systems.

Research staff: Louis A. Ferguson and 6 trained men.

Research work: Part time of 7 on insulation deterioration, potential rises due to switching operations, heat dissipation, electric furnace investigations and storage battery problems.

Unusual equipment: Primary and secondary standardizing instruments, especially for heavy currents; oscillograph and high potential instruments; special generators and transformers; extensive photometric equipment; apparatus for dielectric and insulation tests.

71. **Condensite Company of America,** Bloomfield, N. J. Manufactures synthetic gums, plastic molding preparations and hydrochloric acid.

Research staff: D. S. Kendall and 2 assistants.

Research work: Over one-half time of 3 on improvement and development of phenolic condensation products for industrial uses; development of a protective coating for aeroplane wings; molding compounds for fountain pens.

Unusual equipment: Hydraulic pump and press; vacuum still and vacuum drying oven; mixers, ball mills, impregnating apparatus equipped with vacuum and pressure.

72. **Corn Products Refining Company,** Edgewater, N. J.
Research staff: Christian E. G. Porst, 3 chemical engineers, 4 chemists and 13 helpers and laborers.
Research work: Full time of 21 on problems confined to the industry.

73. **Corning Glass Works,** Corning, N. Y. Makers of technical glass.
Research staff: E. C. Sullivan, 4 chemists, 7 physicists and 4 engineers.
Research work: One-third time of 16 on physical properties of glass as related to chemical composition; lens design; furnace design, refractories; manufacturing problems; and new uses for glass.
Unusual equipment: Facilities for high temperature work.

Corona Chemical Company. See Patton Paint Company.

74. **Cosden & Company,** Tulsa, Okla. Producers and refiners of petroleum.
Research staff: Charles K. Francis and about 50 chemists, physicists, engineers and assistants.
Research work: One-third time of about 50 on petroleum and petroleum products, including gas.
Unusual equipment: General chemical and physical equipment for petroleum work; experimental crude, pressure and steam stills, agitators, tanks, filters, wax presses, sufficient for complete investigation of any crude or semi-refined oil.

75. **Cramp, William, & Sons Ship & Engine Building Co., The,** Philadelphia, Pa. I. P. Morris Hydraulic Laboratory.
Research staff: Frank H. Rogers, 1 machinist, 2 engineers and 2 observers.
Research work: Three-fourths time of 6 in the field of hydraulics and hydrodynamics.
Unusual equipment: Chemical and physical laboratory equipped for work on brasses, bronzes and material testing; under construction a hydraulic testing laboratory, designed especially for hydraulic turbines, centrifugal pumps, etc.; will contain testing flume, tank for rating current meters and similar work, weirs and necessary instruments.

76. **Crane Co.** (Metallurgical Department), 510 Main St., Bridgeport, Conn. and 836 South Michigan Ave., Chicago, Ill. Manufactures valves, pipes, fittings and other supplies for water, gas and steam work.
Research staff (*Bridgeport laboratory*): Allen P. Ford, 2 metallurgists, 1 chemist, 3 assistant chemists and 2 helpers.
Research work: Small part time of 9 on problems connected with the industry.
Unusual equipment: Entirely equipped for routine metallurgical work. 100,000-pound tensile testing machine; transverse, torsion and hardness testing machines.
Research staff (*Chicago laboratory*): L. W. Spring, 1 assistant and 12 men, 2 of whom are doing physical and metallographic testing.
Research work: One-tenth time of 14 on problems connected with the industry.

77. **Crane & Co.,** Dalton, Mass. Paper makers.
Research staff: C. Frank Sammett and 1 chemist.
Research work: Small part time of 2 on improving methods and conditions of manufacture.

Unusual equipment: Well equipped for research and control work pertaining to paper manufacture.

78. **Cudahy Packing Company, The,** South Side, Omaha, Nebr.

Research staff: Wilson H. Low, 10 chemists and 4 workers.

Research work: Part time of 15 on pepsin, pancreatin, glues, curing meats, solutions, and bacterial problems.

79. **Cumberland Mills,** Cumberland Mills, Me. S. D. Warren & Co., Boston, Mass., proprietors. Manufactures pulp and paper.

Research staff: E. Sutermeister, 2 to 4 chemists and 2 or 3 assistants.

Research work: One-third time of 6 on problems relating to pulp and paper industry. Tests of various woods and fibrous materials; studies on soda pulp process and on solubility, adhesive strength and viscosities of caseins and their solutions and coating mixtures; destructive distillation of black liquor and identification of products obtained; studies of expansion of papers with increasing humidity; bleaching studies on sulphite and soda fiber to show effects of variable factors; development of a beating test to show relative strength of fibers; investigations relating to manufacture of satin white; studies of defects in papers and of means to overcome them; tests on factors influencing rosin-sizing of paper; development of a test for sulphur in paper.

Unusual equipment: Small beater; kneader; bleaching equipment; hand moulds; small rotary soda digester; small stationary sulphite digester; pebble mills; Schopper tensile strength tester; Schopper folding tester; Ashcroft testers; Ingersoll glarimeter; Emerson calorimeter; chemical apparatus necessary for inorganic and organic testing analysis and research. Available in mill; 400-pound vertical soda digester; 350-pound beater, and small Fourdrinier paper machine. Apparatus to study foaming of coating mixtures, apparatus to study abrasive qualities of clays and fillers (in process of development).

80. **Curtiss Engineering Corporation, The,** Garden City, N. Y. Curtiss Aerodynamic Research Laboratories. Plant is primarily an experimental plant, devoted to aeronautical research in all forms. Curtiss Aeronautical Library is a very complete collection of aeronautic literature in all languages.

Research staff: J. G. Coffin, 2 wind tunnel operators, 1 aeronautic engineer, 1 model maker and mechanic and 1 motor man.

Research work: Full time of 6 on any special investigation of a theoretical nature; wind tunnel tests of all kinds; tests on new wing sections at various speeds; tests on new models, giving stability and performance before full-size machine is built or flown; tests on streamline forms, such as fuselages, dirigible shapes, flags, propellers, gasoline pumps and generator turbines.

Unusual equipment: Three wind tunnels in operation. (*a*) One large Eiffel type wind tunnel run by a 400-H. P. gasoline motor, electrically controlled; speeds up to 100 miles per hour; balance is specially designed of uni-pivot type, sensitive to less than $^1/_{10,000}$ pound of wind force. (*b*) One 4-ft. wind tunnel of improved type, actuated by a Curtiss OX Motor; specially designed air turbine propeller; special Curtiss type wind tunnel balance; air speeds up to about 80 miles per hour. (*c*) One 2-ft. wind tunnel for qualitative work, run by an electric motor giving wind speeds approximately 30 miles per hour. A completely equipped model-making and instrument-making shop.

81. **Cutler-Hammer Mfg. Co., The,** Milwaukee, Wis. Manufactures electric controlling devices.

Research staff: Arthur Simon, 1 physicist, 2 assistant engineers, 1 assistant physicist, 1 glassblower and mechanical helpers as needed. Has help of Experimental Department with its staff of developing engineers and mechanics.

Research work: Full time of 6 in connection with electrical discharge in gas, particularly evacuated tubes and bearing on control of electric currents.

Unusual equipment: Good equipment of vacuum pumps; glass-blowing shop; testing equipment of electrical nature.

82. **Davis-Bournonville Company,** Jersey City, N. J. Manufactures oxy-acetylene welding and cutting apparatus.

Research staff: Stuart Plumley and 1 chemist.

Research work: Large part time of 2 on oxy-acetylene process and special instruction in apparatus and use of process.

Unusual equipment: A small gas laboratory for acetylene applied to welding and cutting apparatus.

83. **Davison Chemical Company,** Baltimore, Md. Manufactures sulphuric acid.

Research staff: A. E. Marshall and trained research men as required.

Research work: Full time of staff on improvement of manufacturing processes for sulphuric acid and utilization of waste materials.

Unusual equipment: Semi-commercial equipment for development of processes evolved in laboratory.

84. **Dayton Engineering Laboratories Co.,** Dayton, Ohio.

Research staff: J. H. Hunt, 1 research engineer, 4 experimental engineers, 1 chief chemist, 2 chemists and 21 additional members of the staff.

Research work: One-half time of 30 on development of ignition and special electrical equipment for automotive apparatus.

Unusual equipment: Refrigeration plant providing cold-room for starting tests and equipment for delivering 400 cubic feet of air per minute at 0 degrees F. with incoming air 90 degrees F., 70% saturation, used for cold running tests. Dynamometers for engine tests with usual fittings. Oscillograph adapted to use on tests of ignition apparatus.

85. **Dearborn Chemical Company,** McCormick Building, Chicago, Ill. Specialty, scientific boiler feed water treatment.

Research staff: D. K. French and 1 or more chemists and assistants.

Research work: Small part time of 2 on scientific boiler feed water treatment.

Unusual equipment: Mahler Atwater bomb calorimeter, apparatus for mineral, sanitary and bacteriological analyses of water, and for physical and chemical testing of oils.

86. **Dehls & Stein, Inc.,** 237 South St., Newark, N. J. Manufacturing chemists.

Research staff: Dr. L. Stein and 2 chemists.

Research work: One-half time of 3 along lines of fermentology; also production of intermediates for dye-stuff industry.

87. **DeLaval Separator Co., The,** 165 Broadway, New York, N. Y. Makers of centrifugal machinery.

Research staff: Wallace Alexander and 2 assistants.

Research work: Full time of 3 on purifying used oils, clarification and separation of commercial products, making of emulsions, clarification of extracts, purifying of crude and fuel oils, etc.

Unusual equipment: Centrifugal apparatus of all classes.

88. **Detroit Edison Company, The,** Detroit, Michigan. Operating large electric light and power generating and distributing systems.

Research staff: C. F. Hirshfeld, 1 engineer, 2 to 8 trained men, and 4 or more assistants.

Research work: Three-fourths time of about 12 on studies of boiler efficiency and life; condenser and lubrication problems; and furnace design and heat loss investigations.

Unusual equipment: Optical and platinum resistance pyrometers; precision electrical measuring instruments; instruments for furnace and flue tests.

89. **Detroit Testing Laboratory, The,** 674 Woodward Avenue, Detroit, Mich.

Research staff: F. W. Robison and about 20 chemists.

Research work: Major portion of time of 2 or 3 members of staff along manufacturing chemical lines, food problems, possibilities of shale, agricultural problems.

90. **Diamond Match Co., The,** Oswego, N. Y.

Research staff: Frederick Van Dyke Cruser, 7 chemists and chemical engineers, 2 mechanical engineers and 5 assistants.

Research work: One-half time of 15 on problems connected with match manufacture and its allied branches.

91. **Digestive Ferments Company,** Detroit, Mich.

Research staff: Dr. Carl S. Oakman, 6 chemists and 5 bacteriologists.

Research work: Two-thirds time of 12 on physiological and proteid chemistry and commercial classifications of bacteriology.

Unusual equipment: Highly perfected apparatus for the estimation of hydrogen ion concentration.

92. **Dill & Collins Co.,** Richmond and Tioga Sts., Philadelphia, Pa. Paper makers.

Research staff: Frank H. Mitchell, 2 chemists, 2 chemical engineers and 3 assistants.

Research work: One-half time of 1 chemist to full time of 2 chemists on problems of the paper industry.

93. **Doehler Die-Casting Co.,** Court, Ninth and Huntington Sts., Brooklyn, N. Y. Laboratory also at Smead and Prospect Aves., Toledo, Ohio.

Research staff (*Brooklyn laboratory*): Charles Pact, 5 chemists, 6 junior chemists, 1 fuel engineer, 1 steel metallurgist.

Research work: One-fifth time of 14 on problems pertaining directly or indirectly to casting of metals, particularly non-ferrous metals.

Research staff (*Toledo laboratory*): Charles Pact, 1 metallurgist, 1 chemist and 5 junior chemists.

Research work: One-fifth time of 8 on problems pertaining to casting of metals.

Dominion Natural Gas Co., Ltd. See Medina Gas & Fuel Co.

94. **Dorr Company, The,** 101 Park Ave., New York, N. Y. Engineers. Testing plant and laboratory at Westport Mill, Westport, N. Y.

Research staff: John A. Baker, 1 analytical chemist, 1 chemical engineer, 1 mechanical engineer and 4 assistants. In New York office 6 engineers available for advice and work at Westport at intervals.

Research work: Three-fourths time of 8 on extraction of nitrate from caliche, recovering fertilizer from tannery sewage, leaching copper ores, treatment of tin concentrates, investigating a flotation process, and paint grinding.

Unusual equipment: Testing plant and laboratory occupy $2^1/_2$-story building 40 x 80 feet, equipped with bins, small crusher, ball mill and classifier in closed circuit for fine grinding, tanks for agitating, thickeners for decantation, an Oliver filter, a small Wilfley table, flotation machines, and an electric roasting furnace; designed to work out hydrometallurgical problems, and to do work in connection with flotation, leaching, classification, counter-current washing, and trade wastes treatment; equipped to make settling tests to determine size of thickeners needed in sedimentation problems.

95. **Drackett, P. W., & Sons Co., The,** Cincinnati, Ohio. Manufactures acids, alkalis and other heavy chemicals.

Research staff: B. S. Hull, 1 chemist and 1 assistant.

Research work: Development of products and their uses.

96. **Duesenberg Motors Corporation,** Elizabeth, N. J.

Research staff: F. S. Duesenberg and 1 engineer.

Research work: Part time of two on development of internal-combustion motors.

Unusual equipment: Particularly well equipped for testing high-powered engines, and small high speed motors.

97. **du Pont, E. I., de Nemours & Company,** Wilmington, Del. Chemical Department operates four research laboratories in addition to organization at its main office. (Information concerning the entire department is followed by separate accounts of the four laboratories.)

Research staff: Charles L. Reese, 400 graduate chemists and engineers, 221 other salaried employes and 567 payroll employes.

Research work: Practically full time of 1189 on manufacturing operations of the duPont Company, including miscellaneous chemicals, dyes and intermediates, explosives, coated fabrics, plastics, pyroxylin solutions, lacquers, paint and varnish including the production of miscellaneous raw materials as mineral acids and nitrates of soda.

Delta Laboratory, Arlington, N. J.

Research staff: R. P. Calvert, 24 graduate chemists and engineers, 9 other salaried employes and 24 payroll employes.

Research work: Practically full time of 58 on pyralin, pyroxylin solutions, and raw materials therefor.

Unusual equipment: Fairly complete line of semi-manufacturing scale equipment for the experimental manufacture of paper, nitrocellulose and pyralin.

Eastern Laboratory, Box 424, Chester, Pa.

Research staff: A. M. Comey, 39 graduate chemists and engineers, 24 other salaried employes and 135 payroll employes.

Research work: Practically full time of 199 on high explosives and raw materials therefor, processes of manufacture, and methods of testing.

Unusual equipment: Very complete facilities for testing properties of explosives.

Experimental Station, Henry Clay, Del.

Research staff: Hamilton Bradshaw, 84 graduate chemists and engineers, 59 other salaried employes and 193 payroll employes.

Research work: Practically full time of 337 on smokeless powder, black powder, coated fabrics, nitrocellulose, heavy chemicals, paint and varnish—also, miscellaneous, organic and inorganic chemicals and raw materials therefor and manufacturing process and methods of testing.

Unusual equipment: Equipment for experimental manufacture of propellant powders, constant temperature magazines for stability tests and storage of smokeless powder, experimental equipment for the manufacture of coated fabrics, ranges for testing small arms powders for velocity, pressure and accuracy.

Jackson Laboratory, Box 525, Wilmington, Del.

Research staff: Fletcher B. Holmes, 173 graduate chemists and engineers, 53 other salaried employes and 215 payroll employes.

Research work: Practically full time of 442 on dyes and intermediates.

Unusual equipment: Extensive equipment for semi-works operation and investigation of a variety of chemical processes.

98. **Eagle Printing Ink Co., The,** 265 Gates Ave., Jersey City, N. J. Manufactures printing and lithographic inks and dry colors.

Research work: Confined to examination and development of aniline dyes and testing of raw materials.

99. **Eastern Manufacturing Company,** Bangor, Me. Manufactures papers.

Research staff: R. S. Rao, 3 chemists and several assistants.

Research work: Part time of staff on problems connected with paper-making; moisture in loft dried papers before and after calendering.

Unusual equipment: For complete analysis of coal, sulphur, lime caustic, clays, paper, fillers of all descriptions, pigments, dyes. All modern apparatus for coal analysis, small paper beater, apparatus for determining slowness of beater stock, strength of stock in beaters and on finished-paper.

100. **Eastman Kodak Company,** Rochester, N. Y. Manufactures cameras, plates, films and other photographic supplies.

Research staff: C. E. K. Mees, 40 trained men (chemists, physicists, photographic experts); 30 assistants.

Research work: Full time of 71 on theory of photography, development of new photographic materials and methods and study of theory of manufacturing processes. Does not carry on routine testing nor deal with manufacturing problems in general. Since 1913 has published

more than seventy-five scientific communications, dealing chiefly with theory of photography and with applied optics.

Unusual equipment: Full equipment of chemical and physical instruments and a number of special instruments required for photographic sensitometry and manufacture; a complete experimental plant for manufacturing photographic films, plates, papers and emulsions.

101. **Edison, Thomas A., Laboratory,** Orange, N. J.

Research staff: Wm. H. Meadowcroft and a number of helpers.

Research work: Full time of staff on industrial researches confined to problems arising in connection with the company's enterprises. These include manufacture of electrical equipment, storage batteries, sound-recording-and-reproducing devices and Portland cement. Not a research laboratory, as the term is generally understood among engineers and physicists, nor a laboratory for promoting industrial research generally speaking, although engaged in industrial research.

102. **Eimer & Amend,** Third Ave., 18th to 19th Sts., New York, N. Y. Manufacture industrial and educational laboratory apparatus, assayers' materials, chemicals and drugs.

Research staff: C. G. Amend and 3 chemists.

Research work: Large part time of 2 on organic chemicals; special glass apparatus for scientific investigations.

103. **Electrical Testing Laboratories,** 80th St. and East End Ave., New York, N. Y. Operates on a commercial basis and undertakes work for any responsible person or institution.

Research staff: Clayton H. Sharp, 1 chief engineer and 7 research men.

Research work: One-tenth time of 9 on dielectric losses; thermal conductivity of heat insulators at high and low temperatures; radiation efficiency of gas heaters; special cases of electrolysis by stray currents; breakdown voltage of sheet insulation.

Unusual equipment: Very complete for electrical standardizing and research, photometry, mechanical measurements, fuel testing, paper and textile testing, thermometer and pyrometer standardization.

104. **Electro Chemical Company, The,** Dayton, Ohio. Manufactures electrolytic cells for producing sodium hypochlorite.

Research staff: John Gerstle and 1 chemical engineer.

Research work: Two-thirds time of 2 in connection with producing sodium hypochlorite from a sodium chloride solution, principally increasing efficiency of electrolytic cells.

105. **Electro-Metallurgical Company,** Niagara Falls, N. Y.

Research staff: F. M. Becket and 20 men.

Research work: Full time of 21 on metallurgical products, chiefly ferro alloys. Refractories. Problems pertaining to manufacture and use of calcium carbide, ferro alloys and other electric furnace products.

Unusual equipment: Electric furnaces of various types and widely different capacities. Alloy testing and pyrometric equipment. Excellent analytical laboratory facilities.

106. **Ellis, Carleton, Laboratories,** 92 Greenwood Ave., Montclair, N. J.

Research staff: Carleton Ellis and 6 to 12 chemists and engineers.

Research work: Full time of staff on petroleum and vegetable oils,

hydrogenation of oils, organic solvents, gasoline, and a large number of catalytic processes, etc.

Unusual equipment: Mechanical equipment such as mixers, autoclaves, steam-jacketed kettles, filter presses, grinding and crushing machinery, furnaces, etc.

107. **Emerson Laboratory,** 145 Chestnut St., Springfield, Mass.

Research staff: H. C. Emerson and 5 chemists.

Research work: One-fourth time of 6 on paper and textile problems.

108. **Empire Companies, The,** including Empire Gas & Fuel Company, Empire Refineries, Incorporated, Empire Gasoline Company, Empire Pipeline Company, Wichita Natural Gas Company, Producers Refining Company, Standard Asphalt & Refining Company, and various other companies, all subsidiaries of the Cities Service Company, maintain a central chemical organization in charge of general chemical work at the various plants of these companies, and also maintain two general laboratories devoted to chemical research, at Bartlesville and Okmulgee, Okla.

Empire Gas & Fuel Company, Bartlesville, Okla. Also laboratory at Okmulgee.

Research staff: R. M. Isham (Okmulgee laboratory), L. E. Jackson (Bartlesville laboratory) 7 research chemists, and a number of routine chemists and assistants who devote most of their time to plant control work.

Research work: Full time of 9 on problems connected with oil refining, cracking of oils, synthesis of organic compounds, crude petroleum and natural gas. Following laboratory work, semi-commercial apparatus or plant is often built before a large unit or plant is installed.

Empire Gasoline Company, 1st and Wyandotte Aves., Bartlesville, Okla.

Research staff: N. M. Hutchinson, 1 chief technologist, 8 engineers and 33 skilled and unskilled assistants.

Research work: Small part time of 43 on problems arising in oil and gas business, development of new processes and new machines.

109. **Falls Rubber Company, The,** Cuyahoga Falls, Ohio.

Research staff: G. D. Kratz, 4 chemists and 2 engineers.

Research work: One-half time of 5 and one-fourth time of 2 on the investigation of raw rubbers and the process of vulcanization; new machines and mechanical methods.

Unusual equipment: For the study of problems in the vulcanization of rubber.

110. **Firestone Tire & Rubber Company,** Akron, Ohio.

Research staff: John Young, 7 chemists, 6 chemical engineers and 6 mechanical engineers.

Research work: Full time of 20 on development of automobile tires, tubes and rims, and studies of processes and raw materials involved.

111. **Fisk Rubber Company, The,** Chicopee Falls, Mass. Manufactures tires and sundries.

Research staff: R. B. Naylor and 2 chemists.

Research work: Full time of 3, almost entirely organic chemistry.

112. **FitzGerald Laboratories, Inc., The,** Niagara Falls, N. Y.
Research staff: F. A. J. FitzGerald, 4 chemists and assistants.
Research work: One-half time of 5 on thermo-electrochemical problems mainly electric furnace work; studies of heat losses and efficiencies, of carbon and graphite electrode manufacture, of various refractories and methods of manufacturing same. Metallurgical problems involving use of electric furnace.
Unusual equipment: Thermo-electrochemical apparatus, suitable transformers, electric furnace supplies, pyrometers, electrical measuring instruments, etc.

113. **Florida Wood Products Co.,** Jacksonville, Fla. Manufactures phosgene gas.
Research staff: E. B. Smith and 5 or 6 chemists.
Research work: Full time of 6 on development of products of phosgene gas; pharmaceuticals derived from wood products.
Unusual equipment: Special facilities for handling destructive distillation problems, being equipped with iron retorts capacity of 50 pounds to 1500 cubic feet.

114. **Fry, H. C., Glass Company,** and **Beaver Valley Glass Co.,** Rochester, Pa.
Research staff: S. R. Scholes and 2 assistants.
Research work: More than one-half time of 3 on new varieties and compositions of glass. This work is carried out first in small crucible meltings and then in regular factory pots.
Unusual equipment: Large laboratory equipped with traveling crane, motors, air compressors, high-temperature gas-fired furnace of 100 cubic feet capacity.

115. **Gallun, A. F., & Sons Co.,** Milwaukee, Wis. Proprietor, Empire Tannery.
Research staff: J. A. Wilson and 3 trained men.
Research work: Full time of 4 on producing leather more efficiently. Problems are so deeply involved as to include nearly every branch of pure chemistry, but deal especially with the molecular mechanism of the equilibria obtaining when colloid jellies are left in contact with sols and true solutions.
Unusual equipment (in use or planned): Laboratories for investigations involving analyses of leather and materials used in making leather, for electrometric research, dealing especially with measurements of ion concentrations, for work involving microscopy, ultramicroscopy, photomicrography and spectroscopy; fume chamber for practical work giving rise to obnoxious gases; experimental tannery.

116. **General Bakelite Company,** Perth Amboy, N. J. Supplementary laboratory in Yonkers, N. Y.
Research staff: L. H. Baekeland, 2 engineers and 5 chemists.
Research work: Full time of 8, confined almost exclusively to phenol-formaldehyde condensation products, both development and commercial applications.
Unusual equipment: In form of electric ovens, stills, vulcanizers, pebble mills and rubber machinery.

117. **General Chemical Co.,** Research Dept., 25 Broad St., New York, N. Y.

Research staff: H. Wigglesworth and approximately 45 chemists.

Research work: Full time of 46 on improving existing processes of the company, and devising new processes.

Unusual equipment: New research and industrial laboratory just completed.

118. **General Electric Company,** Schenectady, N. Y. Laboratories also at Lynn and Pittsfield, Mass., Harrison, N. J. and Cleveland, Ohio.

Research staff: Willis R. Whitney, 2 assistant directors, 50 chemists, 12 physicists, 13 engineers, 50 research assistants, and machinists, glass-blowers, electricians and clerks.

Research work: Full time of 225 devising new forms of electric lights and improving existing forms. Development of Coolidge X-ray tube. Invention of new and development of existing forms of electric equipment and apparatus. Study of metals and alloys for electrical uses. Wireless transmission development. Study of insulation. Many fundamental physical and chemical scientific researches also are carried on.

Unusual equipment: A 7-story building of 66,500 sq. ft. floor space. Varied, extensive and complete equipment for all kinds of electrical and allied research.

119. **General Motors Corporation,** Detroit, Mich. Manufactures automobiles and accessories. Laboratory serves for inspection as well as development and research. There are four main departments, chemical, metallurgical, electrical and physical.

Research staff: J. M. Lea, 10 chemists, 4 metallurgists, 4 electrical experts and 4 physical testing experts.

Research work: One-fourth time of 23 on analyses of iron, steel and non-ferrous alloys, tests on distillation petroleum products, paints, varnishes, etc.; iron and steel as rolled into shapes, heat-treating and the development of new steels; pyrometers, automobile electrical equipment and storage batteries; engines and automobile accessories.

Unusual equipment: Complete set of physical testing machines and two dynamometers for engine testing and other tests on automobile assemblies. In addition to that of the laboratory, the equipment of constituent plants is available.

120. **General Tire & Rubber Co.,** Akron, Ohio.

Research staff: H. B. Pushee and 4 men.

Research work: One-tenth time of 5 on development of better rubber compounds; rubber accelerators; coefficient of vulcanization.

121. **Glidden Company, The,** Cleveland, Ohio. Manufactures varnishes, enamels, paints, stains.

Research staff: W. M. Waldie, 9 chemists, 2 chemical engineers and a number of physicists. There is a research committee of 3 members, changed from time to time.

Research work: Full time of research committee of 3 on developing synthetic resin, synthetic turpentine, and insecticidal, fungicidal and germicidal products.

Unusual equipment: Fume and boiling stacks, electrical and gas ovens, retorts, disintegrators, spraying apparatus, digestors, and all kinds of apparatus necessary for research in connection with gums, oils and coal tar residues.

122. Globe Soap Co., St. Bernard, Ohio.

Research staff: C. P. Long, 4 chemists and 4 chemical engineers.

Research work: One-tenth time of 9 on problems of the industry.

123. Goodrich, B. F., Company, The, Akron, Ohio. Makes rubber goods of every description.

Research staff: George Oenslager, 1 physicist, 4 chemists and 3 assistants.

Research work: Full time of 9 on study of physical properties of rubber and all materials used directly or indirectly in the industry. Devulcanization of rubber, manufacturing synthetic rubber, accelerators for vulcanizing rubber, and study of great variety of minerals, oils, fats, resins, fabrics, etc., used in rubber goods.

Unusual equipment: Three laboratories. Physical, equipped with compounding mills, vulcanizing presses, vulcanizers, vacuum dryers, ball mills and machines for determining tensile strength and other physical properties of all the materials used; general chemical, and research chemical well equipped for study of problems and fundamental principles in manufacture of rubber goods.

124. Goodyear Tire & Rubber Company, The, Akron, Ohio.

Research staff: C. R. Johnson development manager, J. E. Hale, chief tire designer, in charge of Tire Design Division, K. B. Kilborn, chief experimental engineer, in charge of Machine Design, Mechanical Goods Design and Standards Divisions, R. C. Hartong, chief chemist, in charge of Technical Service and Chemical Divisions, 6 research chemists, 3 research physical chemists and physicists, 7 chemical engineers, 8 assistant engineers, 8 compound development chemists, 24 technical service chemical and mechanical engineers, 24 chemical laboratory chemists and assistant chemists, 24 physical laboratory assistants, 10 machine design engineers, 22 machine designers, 24 machine design detailers and tracers, 49 machine design workshop machinists, 8 foremen and experimental tryout men, 8 mechanical goods design engineers, 10 tire design engineers, 8 tire design assistants. Total employes of department approximately 525.

Research work: Full time of research and development men on mechanism of vulcanization, compounds which affect the rate of vulcanization, development of organic compounds especially adapted to rubber work; application of physical chemistry to study of rubber and compounding materials; physical properties of rubber, and methods of testing and studying them; chemistry of fibrous materials, particularly cotton, and properties of materials used as films or protective agents; industrial processes, such as reclaiming and coagulation of rubber.

Unusual equipment: Chemical equipment includes micrographic and ultra-violet-light apparatus. For chemical engineering there is an industrial laboratory, well equipped with semi-production grinding, sifting and washing apparatus, mixing kettles, autoclaves, condensers, filter presses and other apparatus. Standards division is very completely equipped with apparatus for chemical and physical testing.

125. Gray Industrial Laboratories, The, 961 Frelinghuysen Ave., Newark, N. J.

Research staff: Thomas T. Gray, Frank B. Mason, F. A. Urner and 7 men.

Research work: One-fourth time of 10 on petroleum and its products.
Unusual equipment: Complete semi-commercial oil refining equipment.

126. Great Western Sugar Company, The, Sugar Building, Denver, Colo.
Research staff: W. C. Graham, 1 chief chemist, 4 chemical engineers, 4 research chemists, 2 mechanics, 1 experimental process man, 3 analysts.
Research work: Full time of 16 on investigations of fundamental principles of processes and practices now in use, examination of proposed new processes and apparatus and study of utilization of by-products and waste products; production of crude potash, sodium cyanide, ammonium sulphate and certain rare organic chemicals from the Steffen's waste water; refining of crude potash leading to production of carbonate, hydrate, etc.; production of glycerine by fermentation of waste molasses; recovery of organic acids from waste waters.
Unusual equipment: Complete equipment for manufacture of sugar on a small scale under such conditions that special attention may be paid to any stage of the process.

127. Guggenheim Bros., Chile Exploration Co. Laboratories, 202nd St. and 10th Ave., New York, N. Y.
Research staff: Colin G. Fink, 12 research engineers, 2 analytical chemists and 17 assistants and helpers.
Research work: Almost full time of 32 on metallurgical problems, in particular, electro metallurgical, smelting, leaching, flotation, electrolytic refining, recovery of by-products, insoluble anodes, etc.
Unusual equipment: 1/4 ton Rennerfelt furnace; 1/4 ton Snyder furnace; large electrolytic cells; 12 kw. low volt d. c. generator; complete metallographic outfit.

128. Gulf Pipe Line Company, Houston, Tex. Producers and transporters of petroleum.
Research staff: F. M. Seibert and 4 trained research men.
Research work: Full time of 5 on methods for production and transportation of oil; special problems on treatment of crude oil emulsions, conservation of oil, gas, etc.

129. Gurley, W. & L. E., 514 Fulton St., Troy, N. Y. Makers of instruments for civil, mining and hydraulic engineers, and land surveyors.
Research staff: E. W. Arms, 3 engineers, 3 mechanicians and assistants as needed.
Research work: Practically full time of 7 on investigations for design and manufacture of instruments for civil, mining and hydraulic engineers, such as automatic water stage registers, current meters, hook gages, transits and levels.
Unusual equipment: For testing and calibrating standard precision measures of weight, capacity and length; for investigation of water measurements and for design of instruments for this purpose; automatic water stage registers, current meters and hook gages; special dividing engines for accurate graduation of circles; for drawing platinum wire from 0.001 to 0.00002 inch diameter for cross-wire reticles and in research experiments.

130. **Hamersley M'f'g Co., The,** Garfield, N. J. Manufactures waxed papers.

Research staff: 1 chemical engineer and 7 chemists.

Research work: One-third time of 8 on pulp paper, and paper mill chemicals.

Unusual equipment: Well equipped for general research work; also for paper mill experiments on semi-commercial scale.

131. **Harbison-Walker Refractories Company,** Farmers Bank Building, Pittsburgh, Pa. Manufactures fire-clay, silica, magnesite and chrome bricks and other refractory products.

Research staff: R. H. Youngman, 1 chief chemist, 1 ceramist, 1 or 2 chemists.

Research work: One-third time of 4 on problems in connection with refractories.

Unusual equipment: 1 coal and 1 gas-fired test kiln, air compressor (90 cubic feet per minute at 90 pounds per square inch) 1 motor (18 horse-power) small ore crusher, 2 Braun planetary pulverizers, 1 hydraulic press of 104 tons capacity.

132. **Harrison Safety Boiler Works,** Cochrane Research Laboratories, 17th St. and Allegheny Ave., Philadelphia, Pa., and Earnest, Pa.

Research staff: P. S. Lyon (engineering), J. D. Yoder (chemical), 2 chemists and 5 engineers.

Research work: Full time of 6 on treatment of boiler feed water; experiments on V-notch weirs and other flow meters; water softening; problems in the development of traps, valves, steam and oil separators, etc.

133. **Heinrich Laboratories of Applied Chemistry,** 1001 Oxford St., Berkeley, Cal. (ex Tacoma, Wash.).

Research staff: E. O. Heinrich and 1 chemist.

Research work: Full time of 2 on chemical and photomicrographical problems as applied to criminal investigation.

134. **Hercules Powder Company,** Kenvil, N. J. Manufactures explosives.

Research staff: C. F. Bierbauer and 47 chemists.

Research work: Full time of 48 on explosives, new materials, and related studies.

135. **Hochstadter Laboratories,** 227 Front St., New York, N. Y.

Research staff: Irving Hochstadter and 3 chemists.

Research work: One-half time of 4 on manufacture and preparation of food products with special emphasis on problems relating to drying and desiccation.

Unusual equipment: For drying food products.

136. **Holz & Company, Inc.,** 17 Madison Ave., New York, N. Y.

Research staff: Herman A. Holz and 3 engineers (metallurgical and magnetic).

Research work: Full time of 4 on metallographic problems; correlation of magnetic and mechanical properties of steel.

Unusual equipment: Magnetic and magnetic-mechanical testing apparatus.

137. **Hood Rubber Company,** Watertown, Mass.

Research staff: Warren E. Glancy, 2 chemists and several routine assistants.

Research work: Small part time of staff on new methods of examination of materials; study of various organic derivatives.

Unusual equipment: Latest devices and machines for testing rubber, cloth, yarns; large experimental mill room equipped with heavier machinery and heavier testing machines for testing tires (solid, pneumatic, etc.).

138. **Hooker Electrochemical Co.,** Niagara Falls, N. Y.

Research staff: T. L. Blyster, Director of Development, R. L. Murray, Research Manager, A. H. Hooker, Technical Director, 10 chemists and chemical engineers and 9 assistants.

Research work: Full time of 22 on development of new outlets for chlorine, betterment of present process and manufacture of small tonnage.

Unusual equipment: Furnace room and semi-commercial portion of laboratory built with removable or movable floors to adapt itself to various designs and different sizes of equipment.

139. **Hoskins Manufacturing Company,** 453 Lawton Ave., Detroit, Mich. Manufactures electric furnaces, pyrometers and heating appliances.

Research staff: W. A. Gatward and 4 engineers.

Research work: Almost full time of 5 on the improvement and production of alloys and allied products.

140. **Howard Wheat and Flour Testing Laboratory, The,** Old Colony Building, Minneapolis, Minn.

Research staff: C. H. Briggs and 3 chemists.

Research work: Small part time of 4 on problems connected with causes of peculiar variations of wheats and other cereals when baked into bread or used for other food purposes; efforts to improve methods of separation of wheat proteins; improved methods of quantitative analysis; chemical causes of loaf expansion and effects of various activating materials in bread making, carried out by cooperation of baking and chemical departments. Some work on distinguishing cereal flours one from another.

Unusual equipment: Moisture testers for grain, 4-decimeter S. and H. polarimeter, microscope-polariscope, Duboscq colorimeter, Lovibond tintometer, haemocytometer, yeast testing apparatus of special design, calorimeter, electrical measuring instruments, etc.; wheat and grain cleaning and milling department and a baking test department, equipped for handling more than 100 individual tests daily with automatic control of kneading machines, bread raising cabinets, etc.

141. **Industrial Research Corporation,** 1025 Front St., Toledo, Ohio.

Research staff: C. P. Brockway and 2 engineers.

Research work: Full time of 3 on problems related to small machine equipment and small devices in metal.

142. **Industrial Research Laboratories,** 8 So. Dearborn St., Chicago, Ill.

Research staff: F. Peter Dengler, 2 chemists and 1 engineer.

Research work: Full time of 4 on manufacturing and research problems relative to cement, coal, corn, cotton seed, drugs, dairy, dyes, foods, minerals, paints, paving, petroleum, paper, sewage, soap, steel, sugar, tobacco, water, barley, conservation of waste material.

Unusual equipment: Complete commercial equipment for decolorizing cloth, mill ends, flour bags, sugar bags and all cloth signs. Commercial equipment for extracting vegetable alkaloid from tea and coffee.

143. **Industrial Testing Laboratories,** 402 West 23rd St., New York, N. Y

Research staff: Emil Schlichting and several chemists.

Research work: Small part time of staff on problems connected with fermentation and food industries.

Unusual equipment: For chemical and biological analyses of food and beverages.

144. **Industrial Works,** Bay City, Mich.

Research staff: H. L. Campbell, 2 chemists, and 1 or more assistants.

Research work: Not over one-fifth part time of 5 on development of heat treatment of metals; properties of metals; determining stresses in machine parts; determining properties of materials; control of foundry processes; investigation of welding methods.

Unusual equipment: Shore scleroscope, Berry strain gages; 150,000 pound Riehle testing machine; metallographic outfit.

145. **Inland Steel Company,** Indiana Harbor, Ind.

Research staff: J. C. Dickson, 29 chemists and 5 chemical engineers.

Research work: Full time of 4 and part time of 30 on problems connected with steel industry.

Unusual equipment: Electric and gas furnaces, physical testing machines.

146. **Institute of Industrial Research, The,** 19th and B Sts., N. W., Washington, D. C.

Research staff: Allerton S. Cushman and chemists, physicists and assistants as needed.

Research work: Varying part time of staff on physical testing of cements, rocks, clays, brick, block, iron, steel, wood, rubber, and other materials of construction. In Bitumen Laboratory petroleum and petroleum products, tars and tar products, creosoting oils, asphalts, bituminous emulsions, bituminous aggregates, and all other types of chemical road and paving materials, roofing materials, rubber, etc., are examined and tested. Chemical examinations of rocks, clays, cements, etc., are made and researches conducted on improvements in industrial products and processes and utilization of waste products for road purposes.

Unusual equipment: For cement and bitumen.

147. **International Nickel Co., The,** Bayonne, N. J.

Research staff: Robert J. McKay, 1 metallurgist, 1 assistant metallurgist, 1 chemist, 1 assistant chemist, 1 laboratory assistant, 1 civil engineer, 1 machinist, 1 stenographer and 1 clerk.

Research work: Four-fifths time of 10 on metallurgy of copper and nickel, physical properties of nickel and monel metal, uses of nickel, monel metal and nickel alloys.

Unusual equipment: Laboratory electric furnace equipment for metallurgical experiments. Dust and fume sampling apparatus.

148. **International Silver Company,** Meriden, Conn.

Research staff: Chas. E. Skidgell and 2 chemists.

Research work: Small part time of 3 on electro-plating.

Unusual equipment: For analysis of electro-plating solutions, determination of weights of deposit and similar matters.

149. **Kalmus, Comstock & Westcott, Inc.,** 110 Brookline Ave., Boston, Mass. Consulting and research engineers.

Research staff: Daniel F. Comstock, Physical Research, E. J. Wall, Photographic Chemistry, E. W. Westcott, Chemical Engineering, and chemists, physicists, engineers and assistants, varying from 20 to 30.

Research work: Full time of staff on chemical, electrochemical, metallurgical and photographic lines, leading to development of processes and design and construction of plants.

150. **Keuffel & Esser Co.,** Hoboken, N. J. Manufactures drawing materials and mathematical and surveying instruments.

Research staff: Carl Keuffel, 1 chemist, 2 assistant chemists, 2 optical engineers, and 2 assistants.

Research work: One-half time of 8 on optical glass and various articles manufactured, including design of optical instruments and calculation of optical systems.

Unusual equipment: Special equipment for testing presence of small quantities of iron in silicates, and for physical, chemical and microscopic testing of papers. Optical laboratory equipped for general testing of optical instruments, transmission photometers, special optical benches.

151. **Kidde, Walter, & Company, Incorporated,** 140 Cedar St., New York, N. Y. Engineers and constructors. Research laboratory at Keyport, N. J., at factory of Monmouth Chemical Co., manufacturers of chlorate of potash.

Research staff: E. Schwarz, 1 chief chemist and 2 assistants.

Research work: One-fourth time of 4 on improvements in connection with plant.

152. **Kilbourne & Clark Manufacturing Company,** 20 West Connecticut St., Seattle, Wash. Engineers and manufacturers of electrical apparatus, principally radio telegraph.

Research staff: H. F. Jefferson and 5 men.

Research work: Time of staff as occasion requires, on testing and investigating high-frequency circuits.

Unusual equipment: Wave-meters, decremeters, sphere spark gap (25 C. M. sphere) for high voltage tests; condensers, variable and fixed, with air, mica and oil dielectrics; inductances in various forms for high and low voltage; 500-cycle meters for use in connection with audio-frequency circuits in radio work.

153. **Kistler, Lesh & Company** (Burke Tannery), Morganton, N. C.

Research staff: J. S. Rogers.

Research work: Part time of 1 on chemical problems connected with tanning industry.

Unusual equipment: Laboratory equipped for control and research

connected with tanneries and extract plant; contains regular equipment for leather, tanning materials and liquor analyses.

154. **Klipstein, E. C., & Sons Co.,** So. Charleston, W. Va. Manufactures dyes.

Research staff: Dr. Cabellis and 11 chemists.

Research work: One-half time of 12 on new dyes and their intermediates.

Unusual equipment: Everything necessary for semi-commercial experimental production.

155. **Kokomo Steel and Wire Co.,** Kokomo, Ind.

Research staff: R. K. Clifford, 2 chemists and 2 assistants.

Research work: One-third time of 5 on standardization of raw materials specifications and improvement of products in connection with manufacture of open hearth steel, wire and wire products.

Unusual equipment: Chemical laboratory for the analysis of carbon and special steels, ores, alloys and raw materials, gas, etc. Physical laboratory containing a 100,000-pound Olsen testing machine, a Brinell machine and electric furnace for heat treatments. Metallographic equipment for grinding, polishing and micro-photography. Pyrometer equipment, including Leeds Northrup optical pyrometer.

156. **Kolynos Co., The,** New Haven, Conn. Manufactures dental cream.

Research staff: L. A. Jenkins, 3 chemists and 2 bacteriologists.

Research work: One-half time of 6 on oral hygiene.

Unusual equipment: Chemical and bacteriological laboratories well equipped for pharmaceutical branch of chemistry.

157. **Koppers, H., Company,** Pittsburgh, Pa. Designers and builders of by-products coke and gas oven plants.

Research staff: F. W. Sperr, Jr., 15 men on inside work and 10 men on outside work.

Research work: Full time of 26 on problems closely related to coke ovens and by-products.

Unusual equipment: Laboratories and experimental plant fully equipped for semi-commercial tests, and plants available for large-scale tests.

158. **Kraus Research Laboratories, Inc.,** 130 Pearl St., New York, N. Y. Consulting engineers in refractories.

Research staff: Charles E. Kraus, 2 ceramists, 2 research engineers and 2 assistants.

Research work: Three-fourths time of 7 on ceramics and refractories.

Unusual equipment: Equipped to make all standard tests on refractory materials, both in raw and finished state. High temperature furnaces.

159. **Krebs Pigment and Chemical Co., The,** Newport, Del.

Research staff: H. W. Fox, 2 chemical engineers, 1 chemist and 2 assistants.

Research work: Full time of 6 on properties of lithopone; efficiency of steps of process, barytes ore concentration.

160. **Kullman, Salz & Co.,** Benicia, Cal. Tanners and curriers.

Research staff: Director to be appointed; 1 assistant chemist and 1 helper.

Research work: Variable amount of time of 3 on science of tanning.

161. **Laclede-Christy Clay Products Company,** 4600 S. Kingshighway, St. Louis, Mo.

Research staff: C. W. Berry and 1 assistant.

Research work: One-half time of 2 on development of refractories, superior clays for use in paper, graphite crucibles, enamels; unusual basic and neutral refractories, such as high aluminous materials, combinations of alumina and magnesia.

162. **Larkin Co.,** 680 Seneca St., Buffalo, N. Y. Soap manufacturer.

Research staff: C. B. Morey, 5 chemists and 3 assistants.

Research work: Three-fourths time of 9 on soaps, fats and oils; development along miscellaneous lines of new products for the company.

Unusual equipment: Small experimental plant for producing soap.

163. **Lederle Laboratories,** 39 West 38th St., New York, N. Y.

Research staff: Herbert D. Pease and a number of chemists, bacteriologists and assistants.

Research work: Small part time of staff along sanitary, chemical and bacteriological lines.

Unusual equipment: Well equipped for chemical, bacteriological and some physical work.

164. **Leeds & Northrup Company, The,** 4901 Stenton Ave., Philadelphia, Pa. Makers of electrical measuring instruments.

Research staff: M. E. Leeds, 6 trained men in research work and 2 mechanicians.

Research work: Large part time of 9 on development and use of apparatus for precise measurements in heat, light, electricity, and magnetism; determining projectile velocities, improving depth bombs, perfecting apparatus for submarine detection, perfecting apparatus for bomb sighting, and determining temperature control in ordnance plants.

Lewis Institute. See Structural Materials Research Laboratory.

165. **Lilly, Eli, and Company,** Indianapolis, Ind. Manufactures pharmaceutical and biological products.

Research staff: Frank R. Eldred and about 40 chemists and pharmacologists.

Research work: Full time of 8 men and half time of 17 directed to development of new therapeutic agents and to broad study of mode of action of drugs from physical, chemical and physiological standpoints.

166. **Lincoln, E. S., Inc.,** 534 Congress St., Portland, Me. Consulting engineers; electrical laboratories.

Research staff: E. S. Lincoln and 3 engineers.

Research work: One-fourth time of 4 on power transmission efficiency. Field work a specialty.

167. **Linde Air Products Company,** Buffalo, N. Y.

Research staff: Pierre E. Haynes and 33 men.

Research work: Four-fifths time of 34 on the manufacture of industrial gases.

Unusual equipment: Complete apparatus for analysis of gaseous mixtures by fractionation absorption and gravimetric determination of gaseous density. Pressures available up to 3000 pounds per square inch. Temperatures down to 75 degrees C. absolute.

168. **Lindsay Light Company,** 161 E. Grand Ave., Chicago, Ill.
Research staff: H. N. McCoy, 8 chemists and 1 engineer.
Research work: Four-fifths time of 10 on improvements of processes of refining thorium nitrate, cerium compounds, organic preparations such as phenolphthalein and vanillin, preparation of dyes.

169. **Little, Arthur D., Inc.,** 30 Charles River Road, Cambridge, Mass.
Research staff: G. J. Esselen, Jr., 18 analytical chemists, 10 research chemists and 6 chemical engineers.
Research work: Full time of 10 on paper and pulp, cellulose and its compounds, utilization of lumbering waste, naval stores, potash, soap, metallurgy, application to colloid chemistry.
Unusual equipment: Complete experimental paper mill and other semi-commercial scale equipment.

170. **Littlefield Laboratories Co.,** Seattle, Wash.
Research staff: E. E. Littlefield, 1 electrochemist and electrophysicist, 1 chemist and 1 mechanical engineer.
Research work: Full time of 1 and part time of 3 in chemical, electrical and electrochemical fields; development of special apparatus for initiating and stopping flow of liquids by varying conductivity; electrical treatment of vegetation. Usually done in connection with large industries in the United States and England.

171. **Lockhart Laboratories,** 33 1/2 Auburn Ave., Atlanta, Ga.
Research staff: L. B. Lockhart.
Research work: Two-thirds time of 1 on lubricating oils and greases for automobiles, railroads, etc.; petroleum products, fixed oils, soaps, etc.; also special work on bleaching cotton.

172. **Ludlum Steel Company,** Watervliet, N. Y.
Research staff: P. A. E. Armstrong and 4 trained men.
Research work: Full time of 5 on improvement of manufacturing methods for ferro alloys and certain steels, such as magnet steel, and methods of chemical analysis of steels and ferro alloys.

173. **Lumen Bearing Company,** Buffalo, N. Y. Brass founders.
Research staff: C. H. Bierbaum, metallurgist, B. Woiski, chief chemist, and 2 assistants.
Research work: Varying portion time of 4 on problems in non-ferrous field; interested in microphotography and uncovering new data all the time.
Unusual equipment: 50,000-pound Olsen machine, Brinell machine, scleroscope, etc.

174. **Lunkenheimer Co., The,** Cincinnati, Ohio. Manufactures valves, pipe fittings and other metal specialties.
Research staff: George K. Elliott and 7 assistants.
Research work: Two-fifths time of 8 on metallurgical problems and corrosion. Generation and handling of saturated and super-heated steam; application of arc electric-furnace to production of malleable cast iron, special gray irons, and other high-carbon iron alloys.

175. **MacAndrews & Forbes Company,** 3rd St. and Jefferson Ave., Camden, N. J. Manufactures dyestuffs, wall-board and foamite fire extinguishers.
Research staff: Percy A. Houseman and 7 chemists.

Research work: Three-fourths time of 8 on licorice extract (especially glycyrrhizen), natural dyes (especially hematoxylin from logwood), wall board, box board, and Foamite fire extinguishers.

Unusual equipment: Copper extractors, percolators and vacuum pans of laboratory size and semi-commercial size.

176. **Manhattan Rubber Mfg. Co., The,** Passaic, N. J. Mechanical rubber goods.

Research staff: W. L. Sturtevant, 5 chemists, 5 assistant chemists and 1 engineer.

Research work: One-fourth time of 12 on rubber compounding and vulcanization.

177. **Martin, Glen L., Company, The,** 16800 St. Clair Ave., Cleveland, Ohio. Builders of airplanes.

Research staff: Lessiter C. Milburn, 1 metallurgical engineer and 1 chemist.

Research work: One-third time of 3 on new aircraft materials and check of aircraft designs, aircraft performance tests, and general aircraft development.

Unusual equipment: Rib testing machine (transverse loading distributed according to any pre-determined ratio). Two combined pendulum tension machine and impact test machine, with interchangeable hammers (pendulums) and two ranges of capacity (200 and 1000 pounds).

178. **Martinez Refinery, Shell Co. of California,** Martinez, Cal.

Research staff: A. W. Jurrissen and 2 chemists.

Research work: Varying portion time of 3 on treatment and production of petroleum products.

Unusual equipment: Large scale cracking apparatus and treating plant.

179. **Marvin-Davis Laboratories, Incorporated,** 85 Ninth Ave., New York, N. Y. These are the laboratories of the National Biscuit Company, formerly its Division of Dietetics and Research.

Research staff: Clarke E. Davis, 4 chemists, 2 engineers, 1 baker and 1 assistant.

Research work: One-half time of 9 on food products, their packing and distribution.

180. **Mathieson Alkali Works, (Inc.), The,** Niagara Falls, N. Y.

Research staff: Ralph E. Gegenheimer, 6 chemists and 3 assistants.

Research work: Full time of 4 on chlorination processes, uses for new chlorine products, plant problems in connection with Castner process.

181. **Maynard, T. Poole,** Atlanta, Ga. Geological and industrial engineering.

Research staff: T. Poole Maynard, 1 chemical engineer, 1 mining engineer and 1 civil engineer.

Research work: One-third time of 4 on clays, textiles, oil-cloth; recovery of potash from silicates.

182. **Medina Gas & Fuel Co.,** Cor. Market & North Sts., Wooster, Ohio. Connected with Dominion Natural Gas Co., Ltd., Buffalo, N. Y. Devoted to production and utilization of artificial and natural gas and petroleum.

Research staff: W. G. Leamon and 6 assistants.

Research work: Full time of 7 on gases and oils; new large-scale method of removing hydrogen sulphide from fuel gases; paving asphalt from Mexican petroleum without use of natural asphalts; improvements in absorption methods of extracting natural gas gasolene; vapor pressure phenomena of mixtures of hydrocarbons as found in natural gas gasolene and effects of blending with higher-boiling oils; methods of extracting oil from oil shales; simplifying laboratory practices; volumetric method of technical water analysis; simplified method of technical gas analysis; improved method of determining gasolene content of laboratory-size gas samples.

183. **Mellon Institute of Industrial Research and School of Specific Industries,** University of Pittsburgh, Pittsburgh, Pa.

Research staff: Raymond F. Bacon, 1 associate director, 4 assistant directors, and head of department of research in pure chemistry. Has about 45 industrial fellowships and 65 fellows. Six national trade associations, with a membership of over two thousand firms, have fellowships in the Institute.

Research work: Full time of staff along chemical and engineering lines, more especially chemical.

Unusual equipment: One of the best equipped laboratories in the country, together with outside experimental plants.

184. **Merck & Co.,** 45 Park Place, New York, N. Y. Manufacturing chemists.

Research staff: B. L. Murray and 4 trained chemists.

Research work: Full time of 5 on problems incident to manufacture of the company's products.

Unusual equipment: Standard equipment for research in connection with manufacture of medicinal, analytical, photographic and technical chemicals.

185. **Merrell-Soule Laboratory,** Syracuse, N. Y.

Research staff: R. S. Fleming, 4 chemists and 3 assistants. An engineering department which does much work which might be classified as research.

Research work: Half time of 8 on food problems.

Unusual equipment: Experimental drying plant.

186. **Merrimac Chemical Co.,** North Woburn, Mass.

Research staff: Lester A. Pratt and 5 chemists.

Research work: Full time of 6 on sulphuric, nitric and hydrochloric acids, and inorganic chemicals.

Unusual equipment: Industrial laboratory for carrying on large scale experiments.

187. **Metal & Thermit Corporation,** 120 Broadway, New York, N. Y. Laboratory at Jersey City, N. J.

Research staff: A research council, holding weekly conferences, 1 engineer, 2 supervising chemists, 3 analytical chemists.

Research work: Full time of 6 perfecting processes for the production of rare metals, alloys for industries using ferro-alloys and non-ferrous-alloys, etc.

188. **Metz, H. A., Laboratories, Inc.,** 122 Hudson St., New York, N. Y.

Research staff: Gustave P. Metz and 6 chemists.

Research work: Studies of chemical, pharmaceutical and biological products; dyestuffs and intermediates relating to manufacture of dyestuffs.

Unusual equipment: Chemical apparatus for pharmaceutical, biological, dye and color work.

189. **Midvale Steel Company, The,** Midvale Works, Nicetown, Philadelphia, Pa.

Research staff: A. H. Miller and 17 men.

Research work: One-half time of 18 on investigation of properties of steel, including the establishing of equilibrium diagrams of a number of steel alloys; also investigation of new alloys of steel for use as cutting tools, as ordnance material, and as steel of high tensile characteristics.

Unusual equipment: Apparatus for several methods of obtaining critical temperatures, shock testing machines of Charpy and Izod types, Brinell and Shore hardness testing apparatus, potentiometers and galvanometers used in temperature measurements through the agency of thermocouples; and experimental heat treatment furnaces of both gas and electric types. Research Department also has access to chemical laboratory and testing room, as well as all melting, forging, heat-treating, and machining facilities of plant.

190. **Miller Rubber Co., The,** Akron, Ohio. Manufactures tires and other rubber goods.

Research staff: M. M. Harrison and 5 chemists.

Research work: Full time of 6 on rubber and organic chemistry.

Unusual equipment: Scott fabric tester, Curtis & Marbel fabric inspecting apparatus, tire testing apparatus, etc.; compounding laboratory mill and calendar, experimental press, etc.

191. **Milwaukee Coke & Gas Company, The,** 1st National Bank Building, Milwaukee, Wis.

Research staff: George H. Selke and a number of chemists.

Research work: Full time of 1 to increase efficiency of by-product coke plant; includes heating of ovens, and recovery of light oil, ammonia, gas, etc.

192. **Minneapolis Steel and Machinery Co.,** Minnehaha Ave. & 29th St., Minneapolis, Minn.

Research staff: J. Roy Hoven, chief chemist, 2 chemists, 1 assistant; C. S. Moody, metallurgical engineer, 3 assistants.

Research work: One-fourth time of 8 along the lines of research of steel with exception of melting.

Unusual equipment: 100,000-pound automatic autographic Olsen testing machine, Brinell hardness machine, small electric furnace for temperature up to 1800 degrees F., Leeds and Northrup potentiometer, Leeds and Northrup optical pyrometer, metallographical equipment, Riehle transverse testing machines.

193. **Mojonnier Bros. Co.,** 739 W. Jackson Boulevard, Chicago, Ill. Scientific dairy apparatus and supplies; milk testing.

Research staff: Timothy Mojonnier and J. J. Mojonnier, 1 analyst, 3 chemists and 2 chemists and bacteriologists.

Research work: One-tenth time of 8 on scientific control of milk and milk products, particularly in evaporated and condensed plants,

ice-cream plants and large dairies. Effect of preservatives on composite milk samples; culture, propagation, etc.

Unusual equipment: Mojonnier Model D Milk Tester, containing rapid cooling desiccators; the Mojonnier Model E Culture Controller for the continual propagation and control of pure lactic cultures; sediment tester, acidity and salt tester.

194. **Monsanto Chemical Works,** 1800 South 2nd St., St. Louis, Mo. Manufactures fine and medicinal chemicals, sulphuric and other technical acids, phenol and other heavy chemicals.

Research staff: Jules Bebie, 30 chemists, 4 engineers and 1 safety engineer.

Research work: Full time of 5 or 6 chemists on subjects related to synthetic pharmaceuticals and fine chemicals, including intermediates.

Unusual equipment: Semi-commercial scale experimental laboratory with tanks, stills, agitating kettles, filter press, etc.

195. **Morrill, Geo. H., Co.,** Norwood, Mass. Manufactures printing and lithographic inks, varnish and dry color.

Research staff: Olney P. Anthony and 3 chemists.

Research work: Full time of 4 on dye research.

Unusual equipment: Dye experimental apparatus.

196. **Morris & Company,** Union Stock Yards, Chicago, Ill.

Research staff: J. J. Vollertsen, 2 chemical engineers, 1 chemist and 1 bacteriologist.

Research work: Full time of 5 on industrial investigations of packing house problems and by-products.

197. **Mulford, H. K., Company,** Biological Laboratories, Glenolden, Pa. Manufacturing and biological chemists.

Research staff: John Reichel and 9 persons; in addition, dozens of staff and laboratory assistants engage in some research.

Research work: One-third time of 10 and part time of laboratory staff on problems connected with pharmacology, bacteriology, immunology and serology.

Unusual equipment: Specially equipped for dealing with problems relating to pharmaceutical, biological, biological agricultural work and chemistry of soil, and for bacteriological and serological work. Stock culture department has more than a thousand strains of all bacteria used.

198. **Musher and Company, Incorporated,** Baltimore, Md. Formerly The Pompeian Co.

Research staff: Eugene Bloomberg, 2 chemists and 1 assistant.

Research work: Full time of 4 along general lines of food products with special attention to expression, care and utilization of vegetable oils.

Unusual equipment: Small scale food manufacturing operations, such as expression and filtration of oils.

199. **National Aniline & Chemical Company, Inc.,** 21 Burling Slip, New York, N. Y.

Laboratories at Buffalo and Brooklyn, N. Y. and Marcus Hook, Pa.

Marcus Hook Laboratory, Marcus Hook, Pa.

Research staff: L. P. Kyrides and 9 chemists.

Research work: Almost entirely on dyes and intermediates.

Data concerning the Buffalo and Brooklyn laboratories not received in time for printing.

National Biscuit Company. See Marvin-Davis Laboratories, Inc.

200. **National Canners Association,** 1739 H. St., N. W., Washington, D. C.

Research staff: W. D. Bigelow and 7 chemists, some trained in physics and one in bacteriology.

Research work: One-half to two-thirds time of 8 on study of tin plate from all standpoints; study of causes of spoilage; defective cans; improper management of sealing machine; insufficient temperature or time of sterilization; influence of character of product on penetration of heat to center of can. Study of micro-organisms causing spoilage; abnormal colors on inside surfaces of containers or in contents; conditions leading to rusting or perforation of containers; influence of hard water on hardness or toughness of certain canned vegetables and study of conditions where softening systems would be advisable. Study of waste products, of efficiency of canning devices and operations, especially the conserving of heat. Some of the most effective work has been done in collaboration with other organizations.

Unusual equipment: Special canning equipment with laboratory facilities. Experimental small factory scale cannery and canning laboratory.

201. **National Carbon Company, Inc.,** Cleveland, Ohio. Has two research and development laboratories, one at Cleveland, the other in Fremont, Ohio.

Research staff: H. D. Batchelor; each laboratory has a staff of more than 20 technical men, including chemists, chemical engineers, electrical engineers and physicists.

Research work: Full time of staff on chemical, electrochemical, electrical and physical problems related to company's products.

Unusual equipment: For research and development work connected with manufacture of dry batteries, storage batteries, carbons for electric arc lights, carbon brushes for generators and motors.

202. **National Gum & Mica Co.,** 59th St. and 11th Ave., New York, N. Y.

Research staff: Jerome and Walter Alexander, 3 chemists, 1 chemical engineer and 1 assistant.

Research work: Four-fifths time of 7 on adhesives, colloids, gums, starches, colors, sizings, finishings, etc., for paper and textiles.

203. **National Lamp Works of General Electric Co.,** Nela Park, Cleveland, Ohio. Nela Research Laboratory.

Research staff: Edward P. Hyde, 6 physicists, 1 physiologist, 1 psychologist, 1 mechanician, 1 lamp maker, 1 engineer, 6 assistants and 3 clerks. Outside investigators invited to work in the laboratories; sometimes there have been as many as 7. Charles F. Brush Fellowship in physics.

Research work: Nearly full time of 21 on physics, physiology and psychology of light, particularly in those phases of these sciences which pertain to the science of illumination. Problems to be investigated

group themselves roughly into three classes: 1. Those which have to do with the production of luminous energy; 2. Those which have to do with the utilization of luminous energy; and 3. Those which have to do with the effects of luminous and attendant radiation. Under the first class comes the investigation of the laws of radiation and of the radiating properties of matter. The problems in this class are purely physical. Under the third class comes the investigation of the effects of light and of the attendant radiation on the eye, on the skin, and on microscopic organisms, and of those more subtle but equally important effects of light on our mental phenomena, such as attention, memory and the emotions. Problems of the second class have to do with the absorbing, reflecting, and diffusing properties of matter, the measurement of light, *i. e.*, photometry, and the study of the complex phenomena of color and color sensation. The division having to do with these problems comes into closest contact with illuminating engineering practice. Records of researches are published as papers before the scientific and technical societies and as contributions to the technical journals. Illustrated abstracts of these papers, prepared by the authors, are collected in the Abstract-Bulletin, published by the laboratory.

Glass Development Laboratory.

Research staff: Edward P. Hyde and 5 technical men.

Research work: One-half time of 6 on development work on glass used in connection with the manufacturing of incandescent electric lamps.

Unusual equipment: High-temperature furnace room with both gas and electric furnaces; a physical and optical room with polariscopes, microscopes, spectrometer and other physical apparatus for testing and measuring the mechanical and optical properties of glass.

204. **National Lead Company,** 129 York Street, Brooklyn, N. Y.

Research staff: Gustave W. Thompson, 1 chief chemist, 4 assistants, 9 special investigators and head analysts, 2 paint experts, 8 assistant analysts, 5 laboratory helpers, 6 clerks.

Research work: One-half time of 36 on metals and their products.

Unusual equipment: Howland photometer, complete system identifying all colors on geometric basis; Thompson classifier, for classification of particles of pigments, etc.; special revolving disc apparatus, for measuring strength of whiteness of pigments; special opacimeter for study of opacity of paint films; complete storage battery installation; viscosimeter for oils, automatic recording instrument for cooling curves of alloys; differential cooling curve apparatus; Swedish Brinell Hardness Testing Machine, arrangement for making Baby Brinell hardness tests; Shore scleroscope; Sharples high speed centrifuge; ozone generator; special electric furnaces, etc.

205. **National Tube Company,** Frick Building, Pittsburgh, Pa. Manufactures steel and iron tubes and pipes.

Research staff: F. N. Speller and 6 to 8 men.

Research work: Full time of staff on corrosion of iron and steel under water.

Unusual equipment: Metallographic apparatus and physical testing machines of all kinds.

Nela Research Laboratory. See National Lamp Works of General Electric Co.

206. Nestlé's Food Company, Incorporated, 130 William St., New York, N. Y. Manufactures condensed milk.

Research staff: G. A. Menge, 1 bacteriologist and micologist, 1 chemist and 2 assistants.

Research work: One-half time of 5 on sweetened or unsweetened condensed milk and other products that company produces or may produce.

Unusual equipment: Experimental equipment for production of condensed and evaporated milk; also special analytical and biological equipment adapted to problems pertaining to this industry.

207. New England Confectionery Company, 253 Summer St., Boston, Mass.

Research staff: Edmund Clark and 1 chemist.

Research work: Nine-tenths time of 2 on problems connected with the industry.

208. New Jersey Zinc Company, The, 55 Wall St., New York, N. Y.

Research staff: J. A. Singmaster, 25 chemists, 5 physicists and 50 assistants.

Research work: Full time of 81 on chemical and physical investigations connected with metallurgy of zinc, manufacture and utilization of sulphuric acid and production and properties of worked metallic zinc in shape of sheets, rods, tubes, etc.; also manufacture and use of zinc oxide in rubber and paint industries.

Newlands Laboratories. Organic and sanitary department of The Henry Souther Engineering Co.

209. Newport Turpentine & Rosin Company of Florida, Pensacola, Fla.

Research staff: R. C. Palmer and 2 assistants.

Research work: One-fifth time of 3 on problems relating to the technical and industrial development of terpene and terpene products.

210. Niagara Alkali Co., Niagara Falls, N. Y. Manufactures caustic potash, caustic soda, chlorine products.

Research staff: V. Kokatnur, 1 chief chemist, 2 chemists and 2 assistants.

Research work: Full time of 6 on problems connected with utilization of chlorine; also some fundamental research bearing on main problems.

Unusual equipment: Mercury arc lamp, arc lamp and electric furnace, other electrical equipment; also semi-commercial scale plant.

211. Nichols Laboratories, The, 519 Market St., Knoxville, Tenn. Analytical and industrial chemists and chemical engineers.

Research staff: M. F. Nichols and 1 chemical engineer.

Research work: One-half time of 2 on ores, coals, tanning materials of all kinds, leathers and leather products.

Unusual equipment: Power mills, crushers, pulverizers, electric oven, assay and analytical balances, calorimeter, tintometer, extractors and mechanical shakers.

212. Northwestern Chemical Co., The, Marietta, Ohio. Manufactures chemical automobile utilities.

Research staff: A. S. Isaacs and 2 advisors.

Research work: One-half time of 1 on problems incident to automobile trade and news ink trade; anti-freezing solutions, cements, polishes, dressings and enamels, printers' ink, oil and carbon black.

213. **Norton Company,** Worcester, Mass. Manufactures abrasives and grinding machines.

Research staff: Ross C. Purdy; Analytical Division, 2 chemists and 2 assistants; Ceramic Division, 2 ceramic engineers and 6 or 7 assistants; Organic Division, 1 chemist, 1 expert in plastics and 2 assistants; 1 petrographer; Mechanical Division, 8 mechanical and electrical engineers; Kiln Inspection and Burning Division, 2 men experienced in uses and care of recording pyrometers and 3 assistants.

Research work: Two-fifths time of 31 on investigations of raw materials such as clay, coal, shellac, rubber, oils, paraffins, silicate of soda and abrasives, both natural and artificial; special attention to fire clay and special refractories.

Unusual equipment: Particularly well equipped to do all kinds of work in ceramic research and organic work pertaining to rubber and shellac as binding agents.

214. **Nowak Chemical Laboratories,** 518 Chemical Building, St. Louis, Mo.

Research staff: C. A. Nowak.

Research work: Small part time of 1 on developing new products which can be manufactured without much additional equipment in breweries.

Unusual equipment: Well equipped for brewery and other beverage and food work.

215. **Packard Motor Car Company,** Detroit, Mich. Engineering laboratory.

Research staff: L. M. Woolson, 3 engineers and 1 chemist.

Research work: Full time of 5 on problems connected with Liberty motor, motor trucks and automobiles; automobile and truck chassis development.

Unusual equipment: Complete dynamometer equipment for testing truck, car and airplane engines up to 500 H. P. Complete bench testing equipment for all car, truck and airplane accessories. Automotive power plant and accessories.

216. **Page, Carl M.,** 326 River St., Chicago, Ill. Commercial research and experimental laboratories.

Research staff: Carl M. Page and several chemists, physicists and other assistants.

Research work: Full time of director and part time of others on physical, chemical and metallurgical problems; rubber.

Unusual equipment: Apparatus for work on phenomena of high-potential discharges and vacuum tubes; includes 16-plate static machine 36-inch diameter, one 18-inch and one 10-inch spark X-ray coils with electrolytic and mercury turbine interrupters, one 20,000-volt alternating current transformer with rotary converter, vacuum tube oven, assortment of special tubes, Gaede mercurial air-pump for high vacuum with a Geryk oil-pump as auxiliary. Large special arc lamps for ultra-violet rays; apparatus for work in molecular transformations of hydrocarbon oils; turbine-driven Sharples super-centrifuge, with many accessories of own design; small shop for making special apparatus.

217. **Pantasote Leather Company, The,** Passaic, N. J.
Research staff: Edgar Josephson.
Research work: Full time of 1 on coatings for textiles, rubber coatings for fabrics, oils, paints, varnishes and all closely related industries.

218. **Parke, Davis & Company,** Detroit, Mich. Manufactures drugs and medicines.
Research staff: J. M. Francis, 8 research chemists, 6 chemists on technical tests of materials, 6 pharmacists, several bacteriologists, botanists, pharmacologists, and other specialists and assistants.
Research work: Considerable portion of time of 40 on chemistry, pharmacy, bacteriology, and pharmacology, looking to continued improvement of medicinal products, and problems closely related to development of new remedial agents.

219. **Patton Paint Company,** Milwaukee, Wis. Plants and laboratories at Wilwaukee, Wis., and Newark, N. J. Pitcairn Varnish Company and Corona Chemical Company, both of Milwaukee, are affiliated.
Research staff: A. H. Woltersdorf, Milwaukee laboratory, T. R. Collins, with 2 assistant chemists, Newark laboratory; B. L. Solomon, Pitcairn Varnish Co.; C. B. Dickey, with 2 assistants, Corona Chemical Co.
Research work: Part time of 8 on problems connected with the paint and varnish industry.

220. **Peerless Color Company,** Bound Brook, N. J.
Research staff: R. W. Cornelison and 2 chemists.
Research work: Part time of 3 on problems dealing directly with the manufacture of dyestuffs.

221. **Pennsylvania Railroad Company, The,** Altoona, Pa.
Research work: Small part time of staff on investigation of cause of failure of steel rails; locomotive design; much work in preparation of specifications for various materials; general field of lubrication; water treatment and purification; paints and preservatives; heat treatment of metals, etc. Investigation of electrolysis in systems of underground metallic structures; tests and investigations of the construction of various makes of transformers; tests of various makes of primary and secondary battery cells; oscillographic tests for linear and angular velocity, wave forms, etc.; investigations of special cases of electrical troubles; development of an electrical method of measuring the hardness and homogeneity of steel. Tests of locomotives on the road or tests of equipment with special devices; tonnage rating of trains and following up of all experimental appliances which are put into service for tests purposes. Methods for determination of elements in plain-carbon steels, alloy steels and non-ferrous alloys used for bearing backs and linings, packing-ring metal for different purposes, etc. Examination of fuels, development of specifications for paint products, lubricating and burning oils, boiler compounds, lacquers, plush, car cleaners, cutting compounds, belt dressing, polishing compounds, hydraulic-jack liquids, fuses, track caps, fire-extinguishing preparations, the recovery of used or wasted products, etc.
Unusual equipment: Physical laboratory, six universal tension and compression testing machines, one of 1,000,000, two of 300,000, two of 100,000-pound and one of 150,000-pound capacity; one vibratory

endurance spring testing machine of 75,000-pound capacity; one 43-foot drop-testing machine; two vibrating staybolt testing machines; one Brinell hardness testing machine; one 2000-pound cement testing machine; metallographic equipment.

In the machine room, where sample test specimens are prepared, the following tools are used; two 14-inch engine lathes; one 12-inch drilling lathe; one 24-inch shaper; one 24-inch radial drill; two milling machines for specimens; one 30-inch cold saw; two motor hack saws; two tool grinders; for work in testing air-brake, signal and tank hose and other miscellaneous tests, including steam and hydraulic gages, there are: Six rubber stretching machines; one friction test rack for rubber; one hose mounting machine; one vibrating test rack for hose; one continuous test rack for rubber; four tension testing machines for rubber; one stretching machine for rubber insulation; one spring micrometer machine; one vacuum gage testing machine; one arbor press specimen cutter; one hydraulic gage testing machine, capacity 25,000 pounds per square inch; one dead-weight gage testing machine, capacity six gages; one wiggling testing machine for hose; one bumping testing machine for gages; one whipping testing machine for gages; one hydraulic machine for testing gage glasses.

Rubber, air-brake hose and miscellaneous laboratory, machines for air-brake, signal and tank hose, and other miscellaneous tests, including steam and hydraulic gages, and gage glasses for boilers and lubricators.

Electrical laboratory, equipment for lamp tests consisting of three photometers, lamp test rack of 1000 lamps capacity, with switchboard, transformers and potential regulator equipment.

Manufacturing laboratory for new products, heat treatment laboratory, bacteriology laboratory for water and disinfectants, chemical laboratory.

222. **Pennsylvania Salt Manufacturing Co.,** Greenwich Point, Philadelphia, Pa. Manufacturing chemists and importers of kryolith.

Research staff: A. E. Gibbs, 2 chemical engineers and 3 chemists.

Research work: Practically full time of 6 on problems connected with the industry.

223. **Permutit Company, The,** 440 Fourth Ave., New York, N. Y. Water rectification systems. Factory at Brooklyn, N. Y.

Research staff: T. R. Duggan, 7 chemists and 4 chemical engineers.

Research work: Full time of 2 entirely in connection with water problems and the use and manufacture of artificial zeolites.

224. **Pfaudler Co., The,** Rochester, N. Y.

Research staff: O. I. Chormann, W. F. Zimmerli, 2 chemists, 1 metallurgist and 2 helpers.

Research work: Three-fourths time of 7 on enamels for steel and cast iron; packings; resistivity of enamels, etc.

Unusual equipment: New modern laboratory completely equipped for type of work.

225. **Pfister & Vogel Leather Co.,** 447 Virginia St., Milwaukee, Wis. Tanners and curriers.

Research staff: Louis E. Levi, 3 research chemists and 7 other chemists.

Research work: Full time of 4 on problems related to leather, glue, hair, gelatine, retarder, bitumen, paints, etc.

226. Phelps Dodge Corporation, 99 John St., New York, N. Y. Copper producers.

Research staff: G. D. Van Arsdale, 3 assistants, 1 stenographer and statistical clerk, and 1 laboratory helper.

Research work: Full time of 6 with special attention to leaching, electrolysis, flotation and slag losses of copper.

Unusual equipment: Microphotographic; laboratory-scale flotation and preliminary grinding machines; apparatus and power supply for small-scale leaching and electrolytic tests, etc.

227. Philadelphia Quartz Company, Philadelphia, Pa. Manufactures silicate of soda.

Research staff: James G. Vail, 4 chemists and 1 assistant.

Research work: One-half time of 6 on problems involving application or manufacture of silicate of soda, study of its properties as an adhesive, as an ingredient of acid-proof cement, grinding wheels, soap, asbestos insulating material, coating materials for paper and wooden packages, to prevent the absorption of grease, as an agent in refining of vegetable oils, etc.

Unusual equipment: Crushing and grinding apparatus; two gas-heated furnaces for experiments with fusion, one a small open hearth, and the other a crucible furnace; apparatus for fusion, testing of adhesives, cement, etc., and devices for making the usual commercial tests on paper; small and semi-commercial autoclaves.

Pitcairn Varnish Company. See Patton Paint Company.

228. Pittsburgh Testing Laboratory, 612 Grant St., Pittsburgh, Pa. Laboratories also in New York, N. Y., Detroit, Mich., Birmingham, Ala. and Cincinnati, Ohio.

Research staff: Jas. O. Handy, 26 chemists in Pittsburgh, 2 in New York, 2 in Detroit, 3 in Birmingham and 1 in Cincinnati; 3 mechanical and 3 civil engineers.

Research work: Variable amount time of 41 on wood and drugs (alcohol substitutes, etc.), oil refining (lubricating oil recovery), corrosion resisting metals, water purification, metal extraction from ores, refractory materials (basic).

Unusual equipment: Furnaces, special metallographic equipment, coal distillation apparatus (to be installed), testing machines.

Pompeian Company, The. See Musher and Company, Inc.

229. Portage Rubber Co., The, Barberton, Ohio.

Research staff: R. M. Gage and 2 chemists.

Research work: One-half time of 3 on testing and compounding for rubber goods.

Portland Cement Association. See Structural Materials Research Laboratory.

230. Powers-Weightman-Rosengarten Company, The, 916 Parrish St., Philadelphia, Pa. Manufacturing chemists.

Research staff: George D. Rosengarten and varying number of assistants.

Research work: Variable amount time of staff on improvement of present processes and investigation of new processes.

231. **Prest-O-Lite Co., Inc., The,** Indianapolis, Ind. Manufactures storage batteries; deep drawn seamless steel shells and cylinders; dissolved acetylene for lighting, welding and cutting.

Research staff: J. H. Naiden, 2 trained research workers and 10 laboratory workers.

Research work: Practically full time of 3 on problems connected with the industry, chiefly relating to storage batteries.

Unusual equipment: Motor-generator set; alternating-current equipment for testing electrical machinery; well equipped with portable electrical apparatus; battery experimental room; 2-ton ice machine for cooling box 20 x 10 x 10 feet at 60 degrees F. continuously; storage battery research room.

232. **Providence Gas Company,** Providence, R. I. Manufacturing Department.

Research staff: C. E. Littell, 1 assistant chemist and 3 minor chemists.

Research work: Small part time of 5 on recovery of sulphur from spent oxide, manufacture cyanogen compounds, ammonia compounds, toluol extraction, by-product producers, vertical retort operation and demulsifying tar.

Unusual equipment: Complete apparatus for calorimetry of industrial gases; analyses of gases, coal and coke; investigations on all operating details of gas manufacturing and complete apparatus for investigations of benzol and toluol.

233. **Raritan Copper Works,** Perth Amboy, N. J. Research Department.

Research staff: S. Skowronski, 3 chemists and 1 physicist.

Research work: Full time of 5 on copper metallurgy, electrolytic refining of copper, and recovery of by-products, gold, silver, platinum, palladium, selenium, tellurium, arsenic, nickel, antimony.

234. **Redlands Fruit Products Company,** Redlands, Cal.

Research staff: H. P. D. Kingsbury and 1 chemist.

Research work: Small part time of 2 on fruit products, for example, bottling orange juice.

235. **Redmanol Chemical Products Co.,** 636 West 22nd St., Chicago, Ill. Manufactures acid- and heat-proof varnishes and lacquers, synthetic amber, moulding compounds; for electrical insulation and other uses.

Research staff: L. V. Redman, 5 chemists and 4 engineers.

Research work: One-fourth time of 10 on investigations of insulation plastics, synthetic amber and similar compounds.

236. **Reliance Aniline & Chemical Co., Incorporated,** Poughkeepsie, N. Y.

Research staff: Philip Kaplan and 1 chemist.

Research work: One-third time of 2 along lines of synthetic dyes.

237. **Remington Arms, United Metallic Cartridge Company,** Barnum Ave., Bridgeport, Conn. Research Division.

Research staff: Walter R. Hibbard, 5 chemists, 3 assistant chemists, 1 metallographist, 1 assistant metallographist, 1 pyrometer expert, 2 engineers, 11 miscellaneous.

Research work: One-eighth time of 25 on small arms ammunition.

Unusual equipment: Chemical and metallographic laboratory well equipped for steel treatment, pyrometer testing and calibration, physical testing, etc.

238. **Roessler & Hasslacher Chemical Company, The,** Perth Amboy, N. J.

Research staff: H. R. Carveth and 14 trained research men.

Research work: One-tenth time of 15 on electrolytic processes, including electroplating, manufacture of sodium cyanide and other cyanides, manufacture of peroxides and persalts; bleaching and finishing of textiles; chlorination of organic compounds; manufacture of formaldehyde and its compounds; precious metals, especially gold and platinum; ceramic materials.

239. **Royster, F. S., Guano Company,** Norfolk, Va.

Research staff: E. W. Magruder and 3 chemists.

Research work: Small part time of 4 on fertilizer problems entirely, such as cause of hardening of acid phosphate, effects of different materials on each other when mixed, etc.

Unusual equipment: Excellently equipped for fertilizer work.

240. **Rubber Trade Laboratory,** 325 Academy St., Newark, N. J. An advisory organization, conducting research in industrial establishments; no equipment maintained separately.

Research staff: Frederic Dannerth and 2 chemists.

Research work: One-sixth time of 3 on investigations of new materials used in rubber compounding; industrial researches for developing new materials, new processes and new machinery.

241. **Rumford Chemical Works,** Providence, R. I. Manufacture baking powder, yeast, bread preparation, phosphatic baking acid, acid phosphate and similar products.

Research staff: Augustus H. Fiske, 2 assistant chemists and 5 assistants, 1 librarian and stenographer and 1 miscellaneous worker.

Research work: Equivalent to two-thirds time of 1 on improvement of apparatus for manufacture of phosphoric acid and its salts; improvement of processes of manufacture and of methods of testing products in laboratory.

Unusual equipment: Gas-measuring devices for testing baking powder and specially devised electrolytical apparatus for determination of material by electrolysis.

242. **Sangamo Electric Company,** Springfield, Ill.

Research staff: J. W. Bard, 1 chemist, 2 assistants, 1 electrical engineer and 2 model-makers.

Research work: One-third time of 7 on properties of magnet steels; endurance of material and precious stones used as bearings; paints, varnishes, insulations, brass and steel; development of apparatus employing new principles of operation.

243. **Schoenhofen, Peter, Brewing Company, The,** Chicago, Ill.

Research staff: Henry W. Denny and 3 to 6 chemists, most of whom have had special training along biological lines.

Research work: One-half time of staff on food chemistry; general research in organic chemistry.

Unusual equipment: In control and research laboratories, for foodstuff investigation, both chemical and biological; digesters for high pressure work; Stokes vacuum shelf dryer; Sharples super-centrifuge, air-driven; grinding apparatus; electrically heated and controlled water

baths; Hoskins' electric muffle; Schmidt & Haensch polarimeter (Landolt type); Kober colorimeter-nephelometer, etc. Experimental plant comprises four copper vessels, each of about 150 gallons capacity provided with steam jackets, agitators and the like; also a large cereal grinder; Sperry filter press with montejus; several centrifugal pumps; carbonators; bottling machine; two cold-storage rooms, each 10 x 20 feet.

244. **Schwarz Laboratories,** 200 Worth St., New York, N. Y. Food analyses and research; applied refrigeration; testing of fuels and lubricants.

Research staff: Robert Schwarz, 5 chemists, 1 consulting mechanical engineer and 2 assistants.

Research work: One-fifth time of 9 on food and beverage problems, both chemical and biological.

Unusual equipment: Besides laboratories, a model brewery consisting of grain hoppers, grain mill, pressure cooker of 120 gallons capacity, mixing tub of 120 gallons capacity, two copper kettles, small vacuum evaporator for extraction, and vacuum concentration problems.

245. **Scientific Instrument and Electrical Machine Company, The,** 500 S. York and 221 West Coover Sts., Mechanicsburg, Pa.

Research staff: W. W. Strong and 1 or 2 skilled men.

Research work: Practically full time of 3 on ionization of gases, precipitation of fumes, deblooming oil, nitrogen fixation, diamond surfaced glass, smoke and fume recorders and masks, etc.

Unusual equipment: High voltage apparatus, gratings, ultra-violet apparatus, etc.

246. **Scott, Ernest, & Company,** Fall River, Mass. Engineers, manufacturers of apparatus for saving industrial wastes.

Research staff: H. Austin and Robert W. Macgregor, 4 chemical engineers.

Research work: One-tenth time of 6 on vacuum evaporation, vacuum distilling and solvent extraction.

247. **Scovill Manufacturing Company,** Waterbury, Conn. Manufactures all varieties of brass, bronze, and German silver.

Research staff: Research committee, consisting of D. L. Summey, Chairman, R. S. Sperry and W. B. Price; 1 brass metallurgist with 6 technically trained assistants; 1 steel metallurgist with several technically trained assistants; 1 chief chemist with 50 assistants; superintendent of electrical department and assistants; 1 director of records and statistics for research department with 12 assistants; 1 man in charge of plating and brass finishing, with 2 assistants.

Research work: Full time of about 12 and part time of about 70 on metallurgy of brass, cupro nickel and steel; electric furnace, welding and electrochemical problems; metal finishing; and waste salvage. Much research work is done in the factory, using the large facilities of a plant with 14,000 hands engaged on a great variety of work.

Unusual equipment: Complete metallographic and microscopic apparatus.

Analytical laboratory, electrolytic cabinet, containing 220 positions; capacity of board 2000 assays of copper and lead per 24 hours.

Physical testing apparatus, Olsen 100,000-pound universal automatic

and autographic testing machine, 3-screw type, motor drive, speed 0.025 inch to 6.50 inches a minute; Olsen 50,000-pound universal automatic and autographic testing machine similar to the 100,000-pound machine; Olsen 200,000-pound universal automatic testing machine; Riehle 2,000-pound testing machine, hand drive for tensile tests only; Olsen Brinell hardness testing machine, capacity 3,000 kilograms pressure; Olsen and Erichsen sheet metal testers, for ascertaining ductility; Shore scleroscope.

Electrical laboratory, precision potentiometer and conductivity test set, oscillograph, recording and indicating resistance thermometers and pyrometers.

248. **Sears, Roebuck and Co.,** Chicago, Ill.

Research staff: Don M. Nelson, 14 chemists, 6 laboratory helpers, stenographers and other help.

Research work: Small part time of staff on factory problems and standardization of merchandise.

Semet-Solvay Company. See Solvay Process Co.

Shell Co. of California. See Martinez Refinery.

249. **Solvay Process Company, The,** and **Semet-Solvay Company,** Syracuse, N. Y. Manufacturers of alkali, coke and its by-products. Do research work also for By-Products Coke Corporation, South Chicago, Ill.

Research staff: The Solvay Process Co., Carl Sundstrom, 10 chemists, 5 chemical assistants, 5 clerks and mechanics. Semet-Solvay Co., A. C. Houghton, 22 chemists, 1 chemical engineer, 2 electro-chemical engineers and 12 chemical assistants and routine men.

Research work: Four-fifths time of 20 and one-half time of 37 on soda ash, caustic soda, bicarbonate of soda, lime and limestone, cement, waste disposal, metal corrosion, new alkali products; potash, indigo, fixation of nitrogen, coal, light oils, causticizing, oxalic acid, sulphonation of benzol, picric acid, salicylic acid, chlorination of toluol, benzaldehyde, benzoic acid, and new products, such as diphenyl oxide, benzyl acetate, benzyl benzoate, aspirin, sodium salicylate and cinnamic acid.

Unusual equipment: Electric, steam and gas ovens and furnaces of nearly all sizes up to 2 x 3 x 3 feet, capable of any temperature range up to 1500 degrees C.; temperature measuring equipment ranging from —100 degrees C. to + 1750 degrees C.; laboratory kneading and mixing machine; grinding machinery; 2 autoclaves; apparatus for cement testing; Tyler sieve-shaking machine; Saybolt and Redwood viscosimeters; apparatus for coal testing; gas analysis and photographic apparatus; gas meters and photometer bench; motor-driven pump for gas compression up to 200 pounds per square inch, and hand apparatus up to 10,000 pounds per square inch.

250. **Souther, Henry, Engineering Co., The,** 11 Laurel St., Hartford, Conn. Consulting Engineers.

Research staff: F. P. Gilligan, 13 technically trained assistants and 8 others.

Research work: Small part time of 22 on oils, waters and greases, ferrous and non-ferrous metals, methods of heat-treatment, electroplating, foundry practice, boiler water treatment.

Unusual equipment: Pyrometers, furnaces, lead pot, for experimental heat treatment; 100,000-pound Olsen physical testing machine,

Izod impact tester, White-Souther endurance machines, microphotographic outfit, and lathe, drill-press and other ordinary equipment. In Newlands Sanitary Laboratory, microscopes, refractometer, oil testing equipment, incubators and other chemical and bacteriological apparatus.

251. **Southern Cotton Oil Company, The,** 120 Broadway, New York, N. Y.
Research staff: David Wesson and 1 or 2 assistants.
Research work: Full time of staff on improving methods of analyses on cotton seed products and investigation of catalyzers and their preparation, hydrogenizing fats.

252. **Spencer Lens Company,** Buffalo, N. Y. Research laboratory at Hamburg, N. Y., in optical glass factory.
Research staff: Harry G. Ott and 2 technically trained assistants.
Research work: Large part time of 3 on problems connected with manufacture of various types of optical glass.

253. **Sperry, D. R., & Co.,** Batavia, Ill. Founders and engineers; makers of filter presses and evaporators. Sperry Filtration Laboratory.
Research staff: D. R. Sperry.
Research work: One-fourth time of 1 on systematic effort to determine fundamental laws of filtration.
Unusual equipment: Special filter presses.

254. **Sprague, Warner & Company,** 600 West Erie St., Chicago, Ill. Manufacturers and wholesalers of groceries.
Research staff: Paul D. Potter and 2 trained chemists.
Research work: One-third time of 3 on problems relating to food.

255. **Spreckels Sugar Company,** 60 California St., San Francisco, Cal.
Research staff: R. N. Kennedy, 1 chief chemist, 3 assistant chemists and 6 bench chemists through operating season of three months; 1 chief chemist and 1 assistant chemist in off season of nine months.
Research work: Equivalent of time of 1 man for nine months on extraction and purification of juices; minimization of sugar losses; reduction of fuel-oil, lime and filter-cloth consumption; recovery of potash soda and ammonia compounds from Steffen waste.

256. **Squibb, E. R., & Sons,** New Brunswick, N. J. Research and Biological Laboratories.
Research staff: John F. Anderson, 6 bacteriologists and 3 chemists.
Research work: One-fourth time of 10 on biological and biochemical problems.
Unusual equipment: For the production for commercial purposes, of products for theoretical research in the various phases of biological therapeutics.

257. **Standard Oil Company,** 26 Broadway, New York, N. Y. Central laboratory at Linden, N. J. Other laboratories at principal plants of the Standard Oil Company in the United States and abroad.
Research staff: Frank A. Howard and others.
Research work: Petroleum refining, petroleum products and natural gas.

258. **Stevens, M. T., & Sons Co.,** North Andover, Mass.
Research staff: John F. Bannan, 1 chemist and 2 dyers.
Research work: One-tenth time of 4 on dyeing problems.

259. **Stewart-Warner Speedometer Corporation,** Chicago, Ill. Manufactures speedometers, spark-plugs, vacuum gasoline systems and other automobile accessories.

Research staff: J. E. Genn, 1 inventor and advisory engineer, 1 factory manager and 1 assistant chief engineer.

Research work: Part time of 4 on investigations of fuel feed systems, tachometers and other automobile equipment.

Unusual equipment: For testing tachometer indications at varying temperatures, from 12 to 150 degrees F.; Sprague electric, cradle-type dynamometer, capacity 50 to 75 H. P. 4000 maximum revolutions per minute; Shore scleroscope; Brinell hardness meter; complete equipment for tests and experiments on vacuum feed systems.

260. **Stone & Webster,** 147 Milk St., Boston, Mass. Engineers, constructors, bankers, operators of public utilities.

Research staff: 2 chemists, 2 mechanicians, 1 laborer.

Research work: Full time of 5 on needs of industrial companies, mostly now on zinc.

Unusual equipment: Largely special to research on electrolytic zinc refining.

261. **Strathmore Paper Company,** Mittineague, Mass.

Research staff: Justus C. Sanburn and 1 assistant.

Research work: One-fifth time of 2 on special paper mill problems; sizing paper with rosin.

262. **Structural Materials Research Laboratory, Lewis Institute,** 1951 West Madison St., Chicago, Ill.

Research staff: D. A. Abrams, 5 engineers or physicists, 1 chemist, 7 assistants, 2 stenographers, 2 machinists and 5 laborers.

Research work: Full time of 23 on a variety of problems in cement and concrete.

Unusual equipment: One 200,000-pound and one 40,000-pound screw power Universal testing machine, one 20,000-pound torsion testing machine, one 4-unit Deval abrasion machine for tests of road materials, 1 Standard ball mill for tests of road materials, 1 Ro-Tap sieve shaker for fineness tests of materials, 1 Talbot-Jones rattler for wear tests of concrete, 1 autoclave apparatus for high-pressure steam tests of cement, 1 laboratory crusher, 2 concrete mixing machines; complete equipment for physical tests of cement, aggregates, mortars and concrete.

263. **Studebaker Corporation, The,** Detroit, Mich. Manufactures automobiles and other vehicles.

Research staff: C. Breer; 2 engineers and 1 mechanic in the dynamometer department; 1 electrical engineer and 1 assistant in the electrical department; 1 chemist in the chemical department; 1 engineer, 1 assistant and a staff of mechanics in the road testing department; 1 engineer on special work.

Research work: One-half to two-thirds time of staff on power output of motors, investigations of electrical appurtenances for automobiles, chemical studies of materials used in manufacture, road testing of automobiles, special problems related to radiators, brakes, oil pumps, fans and other equipment of an automobile.

Unusual equipment: Production laboratory has complete me-

chanical, metallurgical and physical testing apparatus, including tensile, torsional and compression machines. Research laboratory: 3 complete electric dynamometer equipments for motors up to 80-horsepower output; completely equipped for investigations of ignition apparatus, lighting and starting apparatus, storage batteries and all other electrical appurtenances of automobiles; apparatus for qualitative analysis of all materials used in manufacture and special equipment for investigating oils and grease; apparatus for unusual problems concerning radiators, brake-linings, oil-pumps, fans and belts.

264. **Titanium Alloy Manufacturing Company, The,** Niagara Falls, N. Y.

Research staff: L. E. Barton, 3 in chemical laboratory, 2 in metallographic and physical testing laboratory, 2 in research and development work in outside steel plants.

Research work: Full time of 8 on problems related to manufacture and use of ferro-carbon-titanium, development of titanox pigments, development of titanium-aluminum bronze.

265. **Toch Brothers,** 320 Fifth Ave., New York, N. Y. Makers of paints, varnishes, colors, enamels; acid, alkali and damp-proof coatings.

Research staff: Maximilian Toch and 4 to 6 chemists.

Research work: One-half time of 1 on problems related to waterproofing and protection of Portland cement by integral and surface coating methods; waterproofing of structural materials.

266. **Tolhurst Machine Works,** Troy, N. Y. Specialists in centrifugals (hydro-extractors).

Research staff: T. A. Bryson, usually 1 engineer and 1 or 2 assistants.

Research work: One-sixth time of 3 on determination of profitable methods of separation (and washing) of liquids from liquids or solids by means of centrifugal force; apparatus for dewatering sewage sludge; separation of foots from oil, recovery of glycerine and salt in soap industry, and improved methods of treating fish and fish oil.

Unusual equipment: Centrifugal machines for filtration, extraction and sedimentation, ranging from small hand-driven, tube and basket centrifuges to higher speed 12 gallons basket capacity centrifugals, with interchangeable baskets of various types for crystalline, granular or fibrous materials, slimes and sludges.

267. **Underwriters' Laboratories,** 207 East Ohio St., Chicago, Ill. Established and maintained by National Board of Fire Underwriters. Departments: Protection, Electrical, Gases and Oils, Chemical, Casualty.

Research staff: W. H. Merrill and 60 experts and necessary assistants.

Research work: An indefinite but large proportion of time of staff on studies of fire-prevention and fire-fighting appliances; welded joints in non-fired pressure containers; rating liquids as to inflammability and explosion hazard; rate of propagation of flame and explosion of various mixtures of gases from volatile liquids with air in piping; explosive ranges of mixtures of hydrogen and oxygen, and of oxygen and hydrogen, at pressures around 2000 pounds per square inch; temperatures of flame of oxy-acetylene welding and cutting burners.

Unusual equipment: Chemical and physical equipment and some electrical apparatus, including that for analysis and physical testing of rubber and gases.

268. **Union Switch & Signal Company,** Swissvale, Pa. Manufactures railway signal equipment. Materials laboratories are maintained separately under the direction of H. C. Loudenbeck, with 12 chemists and C. P. Miller, physicist, with 13 trained men.

Research staff: C. O. Harrington, Jr., and 7 assistants.

Research work: One-third time of 8 on development of iron for electro-magnets, including survey of existing sources and experiments with new alloys; development of best methods of annealing and testing this iron, and determination of standards of acceptance and rejection; selection of materials for, and design of certain special types of, electrical contacts; investigation of proposed methods of testing moulded insulations, including sampling and test of most insulations and porcelains available in this country; development of processes and selection of materials for impregnation of electro-magnet coils and of lumber.

Unusual equipment: Photographic outfit; oscillographs; galvanometers of different sensitivity; numerous pyrometers of varying sensitivities; standardization equipment for electrical instruments; potentiometer; electric muffle furnaces; electric ovens; porcelain tube high-temperature furnace; 50,000-volt insulation testing transformer; hydraulic Brinell machine; Ericsen sheet metal tester; scleroscope; Heissler impact testing machine; 3 Olsen machines having capacities, respectively, 200, 2,000 and 50,000 pounds; an experimental impregnating plant, oil heated, with vacuum and pressure pump.

269. **United Alloy Steel Corporation,** Canton, Ohio. Open hearth and electric steels, bars, slabs, billets, blooms, universal plates.

Research staff: M. H. Schmid, 1 metallurgical engineer, 1 assistant metallurgical engineer, 1 laboratory foreman, 10 assistants and 1 engineer of tests; in the Electric Furnace, 1 chief and 2 recorders; in the Open Hearth Furnace, 1 chief and 8 recorders; in the Rolling Mills, 1 chief and 4 recorders.

Research work: One-half time of 32 on investigations connected with production and use of steel.

Unusual equipment: Heat treatment: 4 Hoskins' electric furnaces, 1 American gas furnace for pieces up to 20 inches length and 5 inches diameter. Physical testing: equipped for tensile, torsion, cold bend, vibratory, Izod, Brinell, scleroscope, staybolt, etc.; also Leeds & Northrup permeameter for determining magnetic permeability of steel and one Leeds & Northrup recalescence instrument for determining critical points of steel. Micro-photography: complete metallographic, photomicrographic and dark-room apparatus.

270. **United Drug Co.,** Boston, Mass.

Research staff: Edward C. Merrill and 15 chemists.

Research work: One-half time of 16, largely on pharmaceutical investigations and research, and independent problems covering miscellaneous subjects.

271. **United Gas Improvement Co., The,** 3101 Passyunk Ave., Philadelphia, Pa.

Research staff: Chas. O. Bond, 3 physicists, 2 engineers, 1 chemist, 4 assistants, office force and mechanic.

Research work: One-half time of staff on color photometry and studies leading to improvement of gas lighting; wider utilizing of gas;

improvement or increase of by-products; studies in the efficiency of light production; results upon various gases of subjecting them to various physical agencies.

Unusual equipment: Light standards, radial, bar and spherical photometers; electrical measurements; pyrometers and heat measuring instruments; calorimeters; gas and electric furnaces; compressors, holders and storage tanks for gas samples; gas analysis apparatus; specific gravity apparatus; life testing racks for gas lamps; vaporizing and condensing apparatus for gas experiments; instrument maker and equipped shop; photograph and microphoto work; Gaede vacuum pump; glass working bench; storage batteries; gas meters and governors and pumps in variety.

272. **United Shoe Machinery Corporation,** Boston, Mass. Laboratory at Beverly.

Research staff: Walter Gould Bullard and assistants.

Research work: Examination of raw materials; extensive tests on core oils and compounds, systematic investigation on improvement in antiseptic quality of cutting compounds and on pickling steel bars and plates.

273. **U. S. Conditioning and Testing Co.,** 316 Hudson St., New York, N. Y.

Research staff: W. F. Edwards, 5 chemists, 3 engineers and 1 physico-chemist.

Research work: One-half time of 10 on investigations of problems arising in textile and allied industries.

Unusual equipment: For investigation of effect of light on dyed textiles.

274. **U. S. Food Products Corp.,** Peoria, Ill.

Research staff: J. K. Dale and 2 chemists; R. Stutyke and 1 engineer.

Research work: Full time of 5 on food development problems.

275. **United States Glue Co.,** Milwaukee, Wis.

Research staff: C. R. McKee and 3 trained men.

Research work: One-half time of 4 on improvements in technology in glue and gelatine industry, particularly development of processes to produce glue and gelatine for various specific purposes, such as gelatine with various photographic properties, food gelatine, marshmallow gelatine and special glue.

Unusual equipment: Complete miniature glue and gelatine factory, dark room for photographic testing and equipment for chemical and biological work.

276. **U. S. Industrial Alcohol Co.,** 27 William St., New York, N. Y. Laboratory at South Baltimore, Md.

Research staff: A. A. Backhaus and 20 or 25 chemists and chemical engineers.

Research work: Full time of staff on research in connection with utilization of alcohol in manufacture of many chemical products, and utilization of by-products of alcohol manufacture.

Unusual equipment: Adequate semi-commercial scale equipment for testing processes developed in chemical laboratory.

277. **United States Metals Refining Co.,** Chrome, N. J.

Research staff: H. D. Greenwood, in charge of chemical department, W. C. Smith, in charge of metallurgical department; about 42 assistants.

Research work: Part time of staff on maintaining a high standard in plant metallurgy and discovering new and improved methods.

Unusual equipment: Chemical, metallurgical and assay equipment. Apparatus for electrolytic determinations. Hoopes conductivity bridge with special balance for weighing wire. Special apparatus for annealing wire. Complete metallographic outfit.

United States Steel Corporation. See Carnegie Steel Company.

278. **Upjohn Company, The,** Kalamazoo, Mich. Makers of fine pharmaceuticals.

Research staff: Frederick W. Heyl, 4 or 5 chemists, 1 pharmacologist, 1 bacteriologist.

Research work: Part time of 7 on estimation of nitroglycerine; analyses of two Echinacea roots; standardization of commercial papain; some constituents of the roots of Brauneria augustifolia; some constituents of Sunbul root; standardization of the mercurials; Algenta root; some constituents of jambul; analysis of ragweed pollen; chemical examination of the leaves of Adonis vernalis; protein extract of ragweed pollen.

279. **Vacuum Oil Company,** Rochester, N. Y. Laboratories also at Olean, N. Y., and Paulsboro, N. J.

Research staff: Florus R. Baxter, 2 chemists at Rochester, 1 chemist at Olean and 1 chemist at Paulsboro.

Research work: One-fifth time of 5 on detection of minute impurities in lubricating oils and perfecting methods for their removal; causes of deterioration of oils in service; elimination and utilization of by-products.

Unusual equipment: Fire, steam and vacuum stills, lead lined agitators fully equipped, wax presses, electric ovens, super-centrifuges, etc.

280. **Victor Chemical Works,** Fisher Building, Chicago, Ill. Large laboratory for factory control and general work and two smaller ones for research.

Research staff: Robert A. Holbrook, 7 chemists and 2 engineers.

Research work: Full time of 8 and one-half time of 2 on problems connected with manufacturing activities.

281. **Wahl-Henius Institute, Incorporated,** 1135 Fullerton Ave., Chicago, Ill.

Research staff: Max Henius, 4 experts, 1 chief analytical chemist, 1 chief research chemist, 3 assistant chemists and 3 assistants.

Research work: Full time of chief research chemist and about one-half time of 1 assistant chemist on fermentation and packing-house problems.

Unusual equipment: Apparatus for testing products of fermentation industries and for carrying out experimental work on semi-commercial scale (experimental brewery, bottlery, etc.). Apparatus for testing solid and liquid fuel, and lubricants; differential refractometer (Tornoe's).

282. **Waltham Watch Company,** Waltham, Mass.
Research staff: F. P. Flagg and 3 chemists.
Research work: Full time of 2 on investigation of the properties of enamel used on watch dials and study of the properties of metals and their relation to watch production.

283. **Warner, William R., & Company, Incorporated,** 113 West 18th St., New York, N. Y. Manufacturing pharmaceutists.
Research staff: L. E. Warren and 2 chemists.
Research work: Full time of 1 and one-half time of 1 on critical study of quantities of alcohol used for extractive and preservative purposes in a number of pharmaceutical preparations.
Unusual equipment: Apparatus for distillation under reduced pressure and for the continuous extraction of drugs under reduced pressure.

Warren, S. D., & Co. See Cumberland Mills.

284. **Washburn-Crosby Co.,** Minneapolis, Minn. Flour mills.
Research staff: Frank W. Emmons, 3 chemists, 1 specially trained physical laboratory man, 1 expert baker and various assistants.
Research work: Full time of 1 on problems relating to wheat flour.
Unusual equipment: All apparatus needed for making analysis on flour and wheat.

285. **Welsbach Company,** Gloucester, N. J. Manufactures mantles for illuminating gas.
Research staff: Harlan S. Miner and 6 trained men.
Research work: One-half time of 7 directed especially to economic production of rare earth chemicals, especially thorium and cerium; manufacture of special rare earth salts, nitration of cellulose, production of mesothorium; radio-chemistry.
Unusual equipment: Especially for the study of problems connected with development of incandescent gas mantles.

286. **Western Aniline Products Company,** 36 South State St., Chicago, Ill. Manufacturers of chemicals and intermediates for dye industry.
Research staff: 1 chemical engineer, 2 chemists.
Research work: Full time of 1 chemist, part time of chemical engineer on the lighter hydrocarbons; special application toluol products.
Unusual equipment: Nitrator, reducer, sulphonater, fractionating still. Electric furnaces, heaters, etc.

287. **Western Electric Company, Incorporated,** 463 West St., New York, N. Y. Laboratories of Western Electric Company are functionally a part of the engineering activities of the whole Bell Telephone System.
Research staff: Frank B. Jewett; H. D. Arnold, Physical Laboratory, with about 10 experts, about 40 college trained men and about 60 laboratory assistants; J. W. Harris, Chemical Laboratory, with 3 or 4 experts and about 20 chemists and laboratory assistants; R. L. Jones, Transmission Laboratory, with several experts, about 30 college trained men, and about 50 laboratory assistants; G. A. Anderegg, Physical Testing Laboratory, with about 40 college trained men and 60 other assistants; about 600 engineers, designers, draftsmen and assistants. Total, about 925.
Research work: Major part time of research staff. In Chemical Laboratory, metallurgical problems include both magnetic and non-

magnetic materials; inorganic products, preservation of timber, very thin and high-grade papers used in telephone condensers. In Physical Research Laboratory problems vary from nature of microphonic action in a telephone transmitter to high vacua phenomena in vacuum tube repeaters and amplifiers; solution of distribution of electric currents in the unsteady state, in circuit networks of a complicated nature; fundamental characteristics of speech transmission.

Unusual equipment: Physical Research Laboratory is equipped for fundamental research in all problems relating to telephony, telegraphy and signaling, including land lines, radio and submarine cable, and practically any line of electrical research which does not involve use of electrical energy in exceedingly large amounts; and physical properties and behavior of materials under conditions of interest to communication engineers.

Chemical Research Laboratory is equipped for organic and inorganic chemistry and has facilities for metallurgical research.

Transmission Research Laboratory, transmission apparatus, particularly transmitters, receivers and associated apparatus.

Physical Testing Laboratory does not carry on fundamental research; has apparatus for physical and engineering tests particularly on communication apparatus and material involved in manufacture of such apparatus.

288. Western Precipitation Company, 1016 West Ninth St., Los Angeles, Cal.

Research staff: H. V. Welch, 1 physicist, 1 engineer, 4 chemists.

Research work: Three-fourths to nine-tenths time of 7 on problems entering around the Cottrell Processes of electrical precipitation.

Unusual equipment: Chemical laboratory, general analytical equipment. Physical laboratory, equipped particularly with high potential electrical apparatus, including 150,000-volt transformer, 50,000-volt direct current generator, high potential mechanical rectifiers, other rectification equipment, measuring instruments, etc., heating equipment and blowers, also small electric furnace. Potash laboratory, digestion and filtration apparatus, including small Oliver filter and special apparatus adapted for study of equilibrium conditions in solutions.

289. Western Sugar Refinery, Foot 23rd St., San Francisco, Cal.

Research staff: S. C. Meredith, 1 chief chemist, 3 engineers, 3 assistant chemists, and 12 workers on routine work.

Research work: Two-fifths time of 8 on investigations of sugar losses, sugar machinery and materials.

290. Westinghouse Church Kerr & Co., Incorporated, 37 Wall St., New York, N. Y.

Research staff: Cloyd M. Chapman and 3 assistants.

Research work: One-half time of 4 cooperating with Am. Soc. Testing Materials on cement, concrete, timber, corrosion of iron and steel, preservative coatings. Load-bearing value of soils for foundations. Analyses of paints, putty and similar materials.

Unusual equipment: Cement and concrete testing apparatus, complete including 200,000-pound hydraulic compression machine, 100,000-pound motor-driven Olsen tension and compression machine.

291. **Westinghouse Electric & Manufacturing Company,** East Pittsburgh, Pa.

Research staff: C. E. Skinner, 1 engineer of research division, 1 manager of engineering, 15 chemists, 15 physicists and 100 mechanics and other assistants.

Research work: Full time of 45 and one-half time of 88 on lamp investigations, incandescent solids, luminous gases, magnetic materials; photomicrographic, electrolytic, metallurgical and photometric investigations; conductivity of metals; linear temperature coefficients; electrical insulation.

Unusual equipment: Five completely equipped laboratories. Routine Chemical, Process, Molded Materials, Electrical, and the Research Building. Also the Standard House.

292. **Westinghouse Lamp Co.,** East Pittsburgh, Pa. Engineering and Development Laboratories at Bloomfield, N. J., under the direction of R. E. Myers with a staff of 87. Research Laboratory at East Pittsburgh.

Research staff: H. C. Rentschler, 2 physicists, 2 assistant physicists and 1 chemist.

Research work: Full time of 6 on study of radiation from solids and gases and vapors; also high vacua phenomena.

Unusual equipment: Apparatus for obtaining and measuring high vacua, for producing high potential rectified current and for photometric and optical pyrometer measurements. High frequency electric furnace. Liquid air available at all times. Rare gases for study of their properties and uses are available.

293. **Weston, Byron, Co.,** Dalton, Mass. Manufactures ledger and record paper.

Research staff: P. W. Codurse and 1 assistant.

Research work: Varying amount time of 2 on problems connected with paper making.

294. **Weston & Sampson,** 14 Beacon St., Boston, Mass. Specialize in water sanitation.

Research staff: R. S. Weston and 1 assistant.

Research work: Small part time of 2 on food problems.

Unusual equipment: Apparatus and facilities for mechanical analysis of filter sands.

295. **Wilson & Co.,** Chicago, Ill. Packers and provisioners. Laboratories at Chattanooga, Tenn., Oklahoma City, Okla., and Kansas City, Mo.

Research staff: L. M. Tolman and 10 assistants.

Research work: One-half time of 11 on problems connected with fermentation, spoilage, etc.; hydrogenation of oils, refining and handling of oils and by-products.

296. **Winchester Repeating Arms Co.,** New Haven, Conn.

Research staff: J. S. Gravely, 8 research chemists, 5 metallurgists and metallographists, 4 electrochemists and engineers, and 32 assistants and routine workers.

Research work: Three-fifths time of 50 on materials and processes involved in the manufacture of small arms and ammunition, cutlery, tools, hardware and sporting goods, dry batteries, flashlights, etc.

297. **Zinsser & Co.,** Hastings-on-Hudson, N. Y.

Research staff: W. A. Lipstate, 6 chemists and 2 chemical engineers.

Research work: Full time of 9 on problems of organic chemistry, intermediates, dyes, medicants, etc.

Unusual equipment: Industrial laboratory completely equipped for semi-factory units.

Geographical Classification of Laboratories Connected with Industrial Establishments

CALIFORNIA
- Benicia
  - Kullman, Salz & Co.
- Berkeley
  - Heinrich Laboratories of Applied Chemistry
- Los Angeles
  - Western Precipitation Company
- Martinez
  - Martinez Refinery, Shell Co. of California
- Oxnard
  - American Beet Sugar Company
- Redlands
  - Redlands Fruit Products Company
- San Francisco
  - Beckman and Linden Engineering Corporation
  - Bethlehem Shipbuilding Corporation, Ltd.
  - Spreckels Sugar Company
  - Western Sugar Refinery

COLORADO
- Denver
  - Great Western Sugar Company, The

CONNECTICUT
- Bridgeport
  - Bridgeport Brass Company
  - Columbia Graphaphone Manufacturing Company
  - Crane Co.
  - Remington Arms, United Metallic Cartridge Company
- Hartford
  - Souther, Henry, Engineering Co., The
- Meriden
  - International Silver Company
- New Haven
  - Kolynos Co., The
  - Winchester Repeating Arms Co.
- Waterbury
  - American Brass Company, The
  - Chase Metal Works
  - Scovill Manufacturing Company

DELAWARE
- Newport
  - Krebs Pigment and Chemical Co., The
- Wilmington
  - Atlas Powder Co.
  - du Pont, E. I., de Nemours, & Co.

D. C., WASHINGTON
- Institute of Industrial Research, The
- National Canners Association

FLORIDA
- Jacksonville
  - Florida Wood Products Co.
- Pensacola
  - Newport Turpentine & Rosin Company of Florida

GEORGIA
- Atlanta
  - American Research Fund
  - Lockhart Laboratories
  - Maynard, T. Poole

ILLINOIS
- Batavia
  - Sperry, D. R., & Co.
- Chicago
  - Armour Glue Works
  - Belden Manufacturing Company
  - Brach, E. J., and Sons
  - Burdett Manufacturing Company
  - By-Products Coke Corporation
  - Central Scientific Company
  - Commonwealth Edison Company
  - Crane Co.
  - Dearborn Chemical Company

Industrial Research Laboratories
Lindsay Light Company
Mojonnier Bros. Co.
Morris & Company
Page, Carl M.
Redmanol Chemical Products Co.
Schoenhofen, Peter, Brewing Company, The
Sears, Roebuck and Co.
Sprague, Warner & Company
Stewart-Warner Speedometer Corporation
Structural Materials Research Laboratory, Lewis Institute
Underwriters' Laboratories
Victor Chemical Works
Wahl-Henius Institute, Inc.
Western Aniline Products Company
Wilson & Co.

La Salle
Carus Chemical Company

Peoria
U. S. Food Products Corp.

Springfield
Sangamo Electric Company

INDIANA

Indiana Harbor
Inland Steel Company

Indianapolis
Lilly, Eli, and Company
Prest-O-Lite Co. Inc., The

Kokomo
Kokomo Steel and Wire Co.

MAINE

Bangor
Eastern Manufacturing Company

Cumberland Mills
Cumberland Mills

Portland
Lincoln, E. S., Inc.

MARYLAND

Baltimore
Bloede, Victor G., Co.
Davison Chemical Company
Musher and Company, Inc.

MASSACHUSETTS

Boston
American Agricultural Chemical Company, The
Associated Factory Mutual Fire Insurance Companies
Boston Bio-Chemical Laboratory, (Inc.), The
Cabot, Samuel, Inc.
Kalmus, Comstock & Westcott, Inc.
New England Confectionery Company
Stone & Webster
United Drug Co.
United Shoe Machinery Corporation
Warren, S. D., & Co.
Weston & Sampson

Cambridge
Little, Arthur D., Inc.

Chicopee Falls
Fisk Rubber Company, The

Dalton
Crane & Co.
Weston, Byron, Co.

Fall River
Scott, Ernest & Company

Holyoke
American Writing Paper Co.

Lawrence
Arlington Mills

Medford
American Radio and Research Corporation

Mittineague
Strathmore Paper Company

North Andover
Stevens, M. T., & Sons Co.

North Woburn
Merrimac Chemical Co.

Norwood
Morrill, Geo. H., Co.

Southbridge
American Optical Company

Springfield
Emerson Laboratory

Waltham
Waltham Watch Company

Watertown
Hood Rubber Company

Worcester
Norton Company

MICHIGAN

Bay City
Industrial Works

MICHIGAN (*Continued*)
Detroit
Berry Bros., Inc.
Detroit Edison Company, The
Detroit Testing Laboratory, The
Digestive Ferments Company
General Motors Corporation
Hoskins Manufacturing Company
Packard Motor Car Company
Parke, Davis & Company
Studebaker Corporation, The
Flint
Champion Ignition Co.
Kalamazoo
Upjohn Company, The
Muskegon
Brunswick - Balke - Collender Co., The

MINNESOTA
Minneapolis
Howard Wheat and Flour Testing Laboratory, The
Minneapolis Steel and Machinery Co.
Washburn-Crosby Co.

MISSOURI
St. Louis
American Zinc, Lead and Smelting Company
Laclede-Christy Clay Products Company
Monsanto Chemical Works
Nowak Chemical Laboratories

MONTANA
Anaconda
Anaconda Copper Mining Co.

NEBRASKA
Omaha
Cudahy Packing Company, The

NEW HAMPSHIRE
Berlin
Brown Company (formerly Berlin Mills Company)
Manchester
Amoskeag Manufacturing Company

NEW JERSEY
Bayonne
Babcock & Wilcox Co., The
International Nickel Co., The
Bloomfield
Condensite Company of America
Boonton
Boonton Rubber Manufacturing Company
Bound Brook
Peerless Color Company
Camden
MacAndrews & Forbes Company
Chrome
United States Metals Refining Co.
Edgewater
Corn Products Refining Company
Elizabeth
Duesenberg Motors Corporation
Garfield
Hamersley M'f'g Co., The
Gloucester
Welsbach Company
Hoboken
Keuffel & Esser Co.
Jersey City
Davis-Bournonville Company
Eagle Printing Ink Co., The
Kenvil
Hercules Powder Company
Montclair
Ellis, Carleton, Laboratories
Newark
Butterworth-Judson Corporation
Dehls & Stein, Inc.
Gray Industrial Laboratories, The
Rubber Trade Laboratory
New Brunswick
Squibb, E. R. & Sons
Orange
Edison, Thomas A., Laboratory
Passaic
Manhattan Rubber Mfg. Co., The
Pantasote Leather Company, The
Perth Amboy
General Bakelite Company
Raritan Copper Works
Roessler & Hasslacher Chemical Company, The
Phillipsburg
Baker, J. T., Chemical Co.

NEW YORK
Auburn
Case Research Laboratory

Binghamton
 Ansco Company
Brooklyn
 Chandler Engineering Corporation
 Doehler Die-Casting Co.
 National Lead Company
Buffalo
 Beaver Company, The
 Buffalo Foundry and Machine Co.
 Dominion Natural Gas Co., Ltd.
 Larkin Co.
 Linde Air Products Company
 Lumen Bearing Company
 National Aniline & Chemical Company, Inc.
 Spencer Lens Company
Corning
 Corning Glass Works
Garden City
 Curtiss Engineering Corporation, The
Hastings-on-Hudson
 Zinsser & Co.
Lackawanna
 Babcock Testing Laboratory
New York
 Abbé Engineering Company
 Aetna Explosives Company, Inc.
 American Can Company
 American Cotton Oil and Associated Cos.
 American Cyanamid Company
 American Leather Research Laboratory
 American Sugar Refining Company, The
 Arbuckle Brothers
 Barrett Company, The
 DeLaval Separator Co., The
 Dorr Company, The
 Eimer & Amend
 Electrical Testing Laboratories
 General Chemical Co.
 Guggenheim Bros.
 Hochstadter Laboratories
 Holz & Company, Inc.
 Industrial Testing Laboratories
 Kidde, Walter, & Company, Inc.
 Kraus Research Laboratories, Inc.
 Lederle Laboratories
 Marvin-Davis Laboratories, Inc.
 Merck & Co.
 Metal & Thermit Corporation
 Metz, H. A., Laboratories, Inc.
 National Biscuit Company
 National Gum & Mica Co.
 Nestlé's Food Company, Inc.
 New Jersey Zinc Company, The
 Permutit Co., The
 Phelps Dodge Corporation
 Schwarz Laboratories
 Southern Cotton Oil Company, The
 Standard Oil Company
 Toch Brothers
 U. S. Conditioning and Testing Co.
 U. S. Industrial Alcohol Co.
 Warner, William R., & Company
 Western Electric Company
 Westinghouse Church Kerr & Co., Incorporated
Niagara Falls
 Acheson Graphite Company
 Carborundum Company, The
 Electro-Metallurgical Company
 FitzGerald Laboratories, Inc., The
 Hooker Electrochemical Co.
 Mathieson Alkali Works (Inc.), The
 Niagara Alkali Co.
 Titanium Alloy Manufacturing Company, The
Oswego
 Diamond Match Co., The
Poughkeepsie
 Reliance Aniline & Chemical Co.
Rochester
 Art in Buttons
 Bausch & Lomb Optical Co.
 Eastman Kodak Company
 Pfaudler Co., The
 Vacuum Oil Company
Schenectady
 General Electric Company
Syracuse
 Merrell-Soule Laboratory
 Semet-Solvay Company
 Solvay Process Company, The
Troy
 Gurley, W. & L. E.
 Tolhurst Machine Works
Watervliet
 Ludlum Steel Company

NORTH CAROLINA

Charlotte
 Charlotte Chemical Laboratories, Inc

NORTH CAROLINA (*Continued*)
Morgantown
Kistler, Lesh & Company

OHIO
Akron
Firestone Tire & Rubber Company
General Tire & Rubber Co.
Goodrich, B. F., Company, The
Goodyear Tire & Rubber Company, The
Miller Rubber Co., The
Barberton
Portage Rubber Co., The
Canton
United Alloy Steel Corporation
Cincinnati
Ault & Wiborg Company, The
Drackett, P. W., & Sons Co., The
Lunkenheimer Co., The
Cleveland
Aluminum Castings Co., The
Cleveland Testing Laboratory Co., The
Glidden Company, The
Martin, Glenn L., Company, The
National Carbon Company, Inc.
National Lamp Works of General Electric Co., Nela Research Laboratory
Cuyahoga Falls
Falls Rubber Company, The
Dayton
Dayton Engineering Laboratories Co.
Electro Chemical Company, The
Marietta
Northwestern Chemical Co., The
Middletown
American Rolling Mill Co., The
St. Bernard
Globe Soap Co.
Toledo
Buckeye Clay Pot Co.
Industrial Research Corporation
Wooster
Medina Gas & Fuel Co.

OKLAHOMA
Bartlesville
Empire Gasoline Company
Empire Gas & Fuel Company
Tulsa
Cosden & Company

PENNSYLVANIA
Altoona
Pennsylvania Railroad Company, The
Arnold
American Window Glass Co.
Bridgeville
American Vanadium Company
Glenolden
Mulford, H. K., Company
Mechanicsburg
Scientific Instrument and Electrical Machine Company, The
Philadelphia
Atlantic Refining Company, The
Baldwin Locomotive Works, The
Cramp, William, & Sons Ship & Engine Building Co., The
Dill & Collins Co.
Harrison Safety Boiler Works
Leeds & Northrup Company, The
Midvale Steel Company, The
Pennsylvania Salt Manufacturing Co.
Philadelphia Quartz Company
Powers - Weightman - Rosengarten Company, The
United Gas Improvement Co., The
Pittsburgh
American Sheet and Tin Plate Co.
Byers, A. M., Company
Carnegie Steel Company
Harbison-Walker Refractories Company
Koppers, H., Company
Mellon Institute of Industrial Research and School of Specific Industries
National Tube Company
Pittsburgh Testing Laboratory
Westinghouse Electric & Manufacturing Company
Westinghouse Lamp Co.
Rochester
Beaver Valley Glass Company and
Fry, H. C., Glass Company
Swissvale
Union Switch & Signal Company

RHODE ISLAND
Providence
Brown & Sharpe Mfg. Co.
Providence Gas Company
Rumford Chemical Works

TENNESSEE
Knoxville
Nichols Laboratories, The

TEXAS
Houston
Gulf Pipe Line Company

VIRGINIA
Norfolk
Royster, F. S., Guano Company

WASHINGTON
Seattle
Kilbourne & Clark Manufacturing Company
Littlefield Laboratories Co.
Tacoma
Bennetts' Chemical Laboratory

WEST VIRGINIA
Charleston
Klipstein, E. C., & Sons Co.

WISCONSIN
Milwaukee
Corona Chemical Company
Cutler-Hammer Mfg. Co., The
Gallun, A. F., & Sons Co.
Milwaukee Coke & Gas Company, The
Patton Paint Company
Pfister & Vogel Leather Co.
Pitcairn Varnish Company
United States Glue Co.

Scientific and Engineering Classification for Laboratories Connected with Industrial Establishments (According to the Kind of Work Done or Connected Industry)

This classification is intended to apply to research laboratories merely for convenience in allocating work or filing information. It has therefore been kept simple. Headings have been taken from *Chemical Abstracts* and *Science Abstracts*, from the names of the laboratories, and from suggestions by members of the Engineering Foundation, the National Research Council and others engaged in research work. Additions can be made as found necessary. Cross-references listed are merely suggestions; they can be increased or cancelled to meet convenience. For the purpose in hand, distinction is made between classifying *laboratories* and classifying scientific and industrial *knowledge*. It is believed that this simple scheme will suffice for the former. Headings are arranged alphabetically; those from *Chemical Abstracts* are designated by *, and those from *Science Abstracts* by @. Some laboratories belong in more than one class. Some of the classes provided have not yet been found necessary.

This classification has been adopted by the Research Committee of the American Society of Mechanical Engineers. It is used in *Mechanical Engineering*, the monthly journal of that Society for reporting in brief the progress and problems of research recorded in current literature.

No.	Class	Cross-references
1.	Abrasives	Carborundum, Emery, Grinding, Polishing, Sandpaper
2.	*Acids, Alkalies, Salts & Sundries	Chemicals (heavy and fine)
3.	Agricultural Equipment & Engineering	Land Drainage, Threshing Machines, Tractors

No.	Class	Cross-references
4.	Air	Air-driven Machines, Air Products, Compressed Air, Liquid Air
5.	Aircraft	Aeronautics, Airplanes, Balloons, Dirigibles (See also Internal Combustion Motors)
6.	*Apparatus & Instruments (Chemical, Physical)	Autoclaves, Balances, Compasses, Gages, Lenses, Microscopes, Telescopes, Transits.
7.	@Astronomy	
8.	Automotive Vehicles & Equipment	Automobiles, Tanks, Tractors, Trucks
9.	Beverages, non-alcoholic	
10.	*Cellulose & Paper	Pulp
11.	*Cement & other Building Materials	Concrete, Marble, Slate
12.	Centrifugals	
13.	*Chemistry, Analytical	
14.	*Chemistry, Biological	Bacteriology, Biology
15.	*Chemistry, General & Physical	
16.	*Chemistry, Inorganic	Carbon, Graphite
17.	*Chemistry, Mineralogical & Geological	Quartz
18.	*Chemistry, Organic	Fermentation, Starch, Vegetable Oils
19.	*Chemistry, Pharmaceutical	Dentifrice, Drugs, Medicine
20.	Computing, Recording & Talking Devices	Adding Machines, Cash Registers, Phonographs, Talking Machines
21.	Concentration of Ores	Flotation
22.	*Dyes & Textile Chemistry	Anilines, Inks, Intermediates, Pigments
23.	Economics	
24.	Electrical Communication	Cable, Telegraph, Telephone, Wireless
25.	Electricity, General	Economics, Insulation, Utilization
26.	Electrical Instruments	Ammeters, Voltmeters, Wattmeters
27.	Electro-plating	
28.	*Electric Power	Conversion, Distribution, Generation, Motors, Plants (power), Transmission
29.	*Electrochemistry	Electro-chemical processes, Storage batteries
30.	*Explosives and Explosions	Dynamite, Powder, TNT
31.	*Fats, Fatty Oils & Soaps	

No.	Class	Cross-references
32.	Fire Prevention	Extinguishers, Sprinklers
33.	*Foods	Bakery, Baking Powder, Biscuit, Butter, Canning, Cold Storage, Flavoring Extracts, Flour, Milk, Oils, Preservatives, Wheat, Yeast
34.	Foundry Equipment, Materials & Methods	Casting, Die Casting, Moulding
35.	*Fuels, Gas, Tar & Coke	Alcohol, Charcoal, Coal, Gasoline, Kerosene, Oil, Peat, Petroleum, Wood
36.	Fuel Utilization	Boilers, Furnaces, Gas-Producers, Stokers
37.	Gases, General	Pneumatics, Poisonous Gas (See also Fuels, and Illumination)
38.	*Glass & Ceramics	Bricks, China, Pottery, Porcelain, Refractories
39.	@ Heat	Calorimetry, Pyrometry, Thermal physics, Thermometry.
40.	Heating	
41.	Hydraulics	Waterworks, Water power
42.	Illumination (Electric, Gas & other)	
43.	Insulation (Electrical and Thermal)	Non-conductors
44.	Internal Combustion Motors	Diesel engine, Gasoline engine, Oil engine
45.	Iron & Steel	Ferrous alloys
46.	*Leather & Glue	Shoes, Boots
47.	@Light	Optical Instruments, Optics (See also Illumination)
48.	*Liquors, Fermented & Distilled	Beer, Wine
49.	Lubricants	Graphite, Oil, Petroleum
50.	Machine Tools	Drill-press, Lathe, Planer, Shaper
51.	@Magnetism	
52.	Marine Engineering	Ships
53.	Mathematics	
54.	Mechanics, General	Bearings (Ball, Roller, etc.)
55.	Metal Manufactures, miscellaneous	Pipes and Fittings
56.	Metallurgy & Metallography	
57.	@Meteorology	
58.	Metrology	Weights and measures

No.	Class	Cross-references
59.	Military & Naval Equipment	Ammunition, Armor, Ordnance, Small Arms, Torpedoes
60.	Mining, General (Testing drills, ropes, tools: Ore dressing)	
61.	Molecular Physics	
62.	Non-ferrous Metals	Aluminum, Brass, Bronze, Copper, Gold, Platinum, Silver, Tin
63.	*Paints, Varnishes & Resins	Dryers, Enamels, Lacquers, Oil, Pigments, Putty
64.	*Petroleum, Asphalt & Wood Products	Linoleum, Oilcloth
65.	*Photography	Cameras, Developers, Films, Moving-picture equipment
66.	@Properties of Engineering Materials	
67.	Pulverizing	Crushing, Grinding
68.	Railroad Rolling-stock & Accessories	Cars, Locomotives
69.	Railroad Tracks & Signals	
70.	Refrigeration	Artificial Ice
71.	Road Materials & Equipment	Highways
72.	*Rubber & Allied Substances	Gutta-percha and substitutes, rubber manufactures
73.	Safety Devices (Transportation, Manufactures, Mines)	
74.	*Soils & Fertilizers	Nitrates, Phosphates
75.	@Sound	Acoustics
76.	Steam Power	Boilers, Economizers, Engines, Turbines
77.	*Subatomic Phenomena & Radio-activity	
78.	*Sugar	Sorghums, Syrups
79.	Surgical, Dental & Hospital Equipment	
80.	Textile Manufacture & Clothing	Cotton, Linen, Wool
81.	Transmission	See also Electric Power
82.	Ventilation	
83.	*Water, Sewage & Sanitation	
84.	Welding (Autogenous, gas, electric, forge)	
85.	Wood Products (other than Cellulose & Paper)	See also Cellulose and Paper

Cross-references

Cross-references (*Continued*)

Scientific and Engineering Classification of Laboratories Connected with Industrial Establishments

ABRASIVES

Carborundum Company, The
Norton Company
Nowak Chemical Laboratories
Scovill Manufacturing Company

ACIDS, ALKALIES, SALTS AND SUNDRIES

du Pont, E. I., de Nemours & Company
Hooker Electrochemical Co.
Mathieson Alkali Works (Inc.), The
Merrimac Chemical Co.
Niagara Alkali Co.
Pennsylvania Salt Manufacturing Co.
Powers-Weightman-Rosengarten Company, The
Solvay Process Company, The

AIR

Linde Air Products Company
Packard Motor Car Company

AIRCRAFT

Curtiss Engineering Corporation, The
Martin, Glenn L., Company, The
Packard Motor Car Company

APPARATUS AND INSTRUMENTS

Baldwin Locomotive Works, The
Bethlehem Shipbuilding Corporation, Ltd.
Brown & Sharpe Mfg. Co.
Central Scientific Company
Cutler-Hammer Mfg. Co., The
Eimer & Amend
FitzGerald Laboratories, Inc., The
Fry, H. C., Glass Company
Gurley, W. & L. E.
Industrial Research Corporation
Keuffel & Esser Co.
Leeds & Northrup Company, The
Lunkenheimer Co., The
Minneapolis Steel and Machinery Co.
Sangamo Electric Company
Scientific Instrument and Electrical Machine Company, The
Studebaker Corporation, The
Tolhurst Machine Works
Waltham Watch Company

AUTOMOTIVE VEHICLES AND EQUIPMENT

Northwestern Chemical Co., The
Packard Motor Car Company

BAKELITE AND CONDENSITE

Condensite Company of America
General Bakelite Company

CELLULOSE AND PAPER

American Writing Paper Co.
Beaver Company, The
Brown Company (formerly Berlin Mills Company)
Crane & Co.
Cumberland Mills
Dill & Collins Co.
du Pont, E. I., de Nemours & Company
Eastern Manufacturing Company
Emerson Laboratory

Hammersley M'f'g Co.
Little, Arthur D., Inc.
Maynard, T. Poole
Strathmore Paper Company
Weston, Byron, Co.

CEMENT AND OTHER BUILDING MATERIALS

Buckeye Clay Pot Co.
Industrial Research Laboratories
Institute of Industrial Research, The
Structural Materials Research Laboratory, Lewis Institute
Toch Brothers
Westinghouse Church Kerr & Co., Inc.

CENTRIFUGALS

De Laval Separator Co., The
Tolhurst Machine Works

CHEMISTRY, ANALYTICAL

American Optical Company
Armour Glue Works
Bridgeport Brass Company
Carborundum Company, The
Drackett, P. W., & Sons Co., The
General Bakelite Company
General Motors Corporation
Industrial Testing Laboratories
Kidde, Walter, & Company, Incorporated
Little, Arthur D., Inc.
Marvin-Davis Laboratories, Incorporated
Merck & Co.
Nichols Laboratories, The
Pantasote Leather Company, The
Scovill Manufacturing Company

CHEMISTRY, BIOLOGICAL

Bennetts' Chemical Laboratory
Boston Bio-Chemical Laboratory (Inc.), The
Dehls & Stein, Inc.
Digestive Ferments Company
Kolynos Co., The
Lederle Laboratories
Merrell Soule Laboratory
Morris & Company
Mulford, H. K., Company
National Canners Association
Parke, Davis & Company
Schoenhofen, Peter, Brewing Company, The
Sprague, Warner & Company
Squibb, E. R., & Sons
United States Glue Co.
Upjohn Company, The
Weston & Sampson
Wilson & Co.

CHEMISTRY, GENERAL AND PHYSICAL

Art in Buttons, Incorporated
Edison, Thomas A., Laboratory
Kalmus, Comstock & Westcott, Inc.
Little, Arthur D., Inc.
Littlefield Laboratories Co.
Mellon Institute of Industrial Research
Victor Chemical Works
Western Precipitation Company

CHEMISTRY, INORGANIC

Acheson Graphite Company
American Writing Paper Co.
Babcock & Wilcox Co., The
Baker, J. T., Chemical Co.
Burdett Manufacturing Company
Carus Chemical Company
Chandler Engineering Corporation
Cumberland Mills
Davison Chemical Company
Dearborn Chemical Company
Detroit Testing Laboratory, The
Drackett, P. W., & Sons Co., The
FitzGerald Laboratories, Inc., The
General Chemical Co.
Industrial Research Laboratories
Lindsay Light Company
Little, Arthur D., Inc.
Merrimac Chemical Co.
National Gum & Mica Co.
Permutit Company, The
Pittsburgh Testing Laboratory
Squibb, E. R., & Sons

CHEMISTRY, MINERALOGICAL AND GEOLOGICAL

Philadelphia Quartz Company

CHEMISTRY, ORGANIC

American Cotton Oil and Associated Cos.
American Research Fund
Arlington Mills

Baker, J. T., Chemical Co.
Beckman and Linden Engineering Corporation
Bennetts' Chemical Laboratory
Bloede, Victor G., Co.
Burdett Manufacturing Company
Carus Chemical Company
Chandler Engineering Corporation
du Pont, E. I., de Nemours & Company
Ellis, Carleton, Laboratories
General Chemical Co.
Industrial Research Laboratories
Lindsay Light Company
Little, Arthur D., Inc.
Musher and Company, Incorporated
National Gum & Mica Co.
Pittsburgh Testing Laboratory
Southern Cotton Oil Company, The
Spreckels Sugar Company
Squibb, E. R., & Sons
Western Sugar Refinery
Zinsser & Co.

CHEMISTRY, PHARMACEUTICAL

American Research Fund
Cudahy Packing Company, The
Eimer & Amend
Heinrich Laboratories of Applied Chemistry
Kolynos Co., The
Larkin Co.
Lilly, Eli, and Company
Merck & Co.
Metz, H. A., Laboratories, Inc.
Monsanto Chemical Works
Mulford, H. K., Company
Parke, Davis & Company
Pittsburgh Testing Laboratory
Squibb, E. R., & Sons
United Drug Co.
Upjohn Company, The
Warner, William R., & Company, Incorporated
Zinsser & Co.

COMPUTING, RECORDING AND TALKING DEVICES

Columbia Graphophone Manufacturing Company
Edison, Thomas A., Laboratory

DYES & TEXTILE CHEMISTRY

Amoskeag Manufacturing Company
Arlington Mills
Ault & Wiborg Company, The
Butterworth-Judson Corporation
Dehls & Stein, Inc.
du Pont, E. I., de Nemours & Company
Eagle Printing Ink Co., The
Klipstein, E. C., & Sons Co.
MacAndrews & Forbes Company
Metz, H. A., Laboratories, Inc.
Morrill, Geo. H., Co.
National Aniline & Chemical Company, Inc.
Peerless Color Company
Reliance Aniline & Chemical Co., Incorporated
Roessler & Hasslacher Chemical Company, The
Sears, Roebuck and Co.
Semet-Solvay Company
Stevens, M. T., & Sons Co.
U. S. Conditioning and Testing Co.
Western Aniline Products Company
Zinsser & Co.

ELECTRICAL COMMUNICATION

American Radio and Research Corporation
Kilbourne & Clark Manufacturing Company
Western Electric Company, Incorporated
Westinghouse Electric & Manufacturing Company

ELECTRICITY, GENERAL

Belden Manufacturing Company
Cutler-Hammer Mfg. Co., The
Edison, Thomas A., Laboratory
General Electric Company
Page, Carl M.
Western Electric Company, Incorporated
Westinghouse Electric & Manufacturing Company

ELECTRICAL INSTRUMENTS

Cutler-Hammer Mfg. Co., The
Hoskins Manufacturing Company
Leeds & Northrup Company, The
Scientific Instrument and Electrical Machine Company, The

ELECTRIC POWER

Champion Ignition Co.
Commonwealth Edison Company
Dayton Engineering Laboratories Co.
Detroit Edison Company, The
General Electric Company
Lincoln, E. S., Inc.
National Carbon Company, Inc.

ELECTROCHEMISTRY

Beckman and Linden Engineering Corporation
Charlotte Chemical Laboratories, Inc.
Electro Chemical Company, The
Electro-Metallurgical Company
FitzGerald Laboratories, Inc., The
Guggenheim Bros.
Hooker Electrochemical Co.
International Silver Company
Kalmus, Comstock & Westcott, Inc.
Littlefield Laboratories Co.
National Carbon Company, Inc.

EXPLOSIVES AND EXPLOSIONS

Aetna Explosives Company, Inc.
Atlas Powder Co.
Barrett Company, The
du Pont, E. I., de Nemours & Company
Hercules Powder Company

FATS, FATTY OILS AND SOAPS

American Cotton Oil and Associated Cos.
Arlington Mills
Globe Soap Co.
Larkin Co.
Little, Arthur D., Inc.
Lockhart Laboratories
Mojonnier Bros. Co.

FIRE PREVENTION

Associated Factory Mutual Fire Insurance Companies
MacAndrews & Forbes Company
Underwriters' Laboratories

FOODS

American Can Company
American Cotton Oil and Associated Cos.
Babcock Testing Laboratory
Brach, E. J., and Sons'
Cleveland Testing Laboratory Co., The
Corn Products Refining Company
Cudahy Packing Company, The
Detroit Testing Laboratory, The
Hochstadter Laboratories
Howard Wheat and Flour Testing Laboratory, The
Industrial Research Laboratories
Lederle Laboratories
Marvin-Davis Laboratories, Incorporated
Merrell-Soule Laboratory
Mojonnier Bros. Co.
Morris & Company
Musher and Company, Incorporated
National Canners Association
Nestlé's Food Company, Incorporated
New England Confectionery Company
Pittsburgh Testing Laboratory
Redlands Fruit Products Company
Rumford Chemical Works
Schoenhofen, Peter, Brewing Company, The
Schwarz Laboratories
Sears, Roebuck and Co.
Sprague, Warner & Company
U. S. Food Products Corp.
Wahl-Henius Institute, Incorporated
Washburn-Crosby Co.
Weston & Sampson
Wilson & Co.

FOUNDRY EQUIPMENT, MATERIALS AND METHODS

Aluminum Castings Co., The
American Brass Company, The
Buffalo Foundry and Machine Co.
Crane Co.
Doehler Die-Casting Co.

FUELS, GAS, TAR AND COKE

Arlington Mills
Atlantic Refining Company, The
Barrett Company, The
Cosden & Company
Dearborn Chemical Company
Empire Companies, The
Gray Industrial Laboratories, The
Gulf Pipe Line Company
Industrial Research Laboratories
Koppers, H., Company
Lockhart Laboratories

Martinez Refinery, Shell Co. of California
Medina Gas & Fuel Co.
Milwaukee Coke & Gas Company, The
Nichols Laboratories, The
Providence Gas Company
Schoenhofen, Peter, Brewing Company, The
Spreckels Sugar Company
Standard Oil Company
United Gas Improvement Co., The
Vacuum Oil Company

FUEL UTILIZATION

Babcock & Wilcox Co., The
Harrison Safety Boiler Works

GASES, GENERAL

Burdett Manufacturing Company
Linde Air Products Company

GLASS AND CERAMICS

American Window Glass Co.
Babcock Testing Laboratory
Bausch & Lomb Optical Co.
Beaver Valley Glass Company
Buckeye Clay Pot Co.
Carborundum Company, The
Champion Ignition Co.
Corning Glass Works
Electro-Metallurgical Company
Fry, H. C., Glass Company
Harbison-Walker Refractories Company
Hoskins Manufacturing Company
Keuffel & Esser Co.
Kraus Research Laboratories, Inc.
Laclede-Christy Clay Products Company
Maynard, T. Poole
Norton Company
Nowak Chemical Laboratories
Pfaudler Co., The
Pittsburgh Testing Laboratory
Spencer Lens Company
Waltham Watch Company

HEAT

Bethlehem Shipbuilding Corporation, Ltd.
Commonwealth Edison Company
General Motors Corporation
Leeds & Northrup Company, The
Wahl-Henius Institute, Incorporated

HYDRAULICS

Associated Factory Mutual Fire Insurance Companies
Harrison Safety Boiler Works

ILLUMINATION (Electric, Gas & Other)

Burdett Manufacturing Company
Electrical Testing Laboratories
National Carbon Company, Inc.
National Lamp Works of General Electric Co.
Page, Carl M.
Prest-O-Lite Co., Inc., The
Providence Gas Company
United Gas Improvement Co., The
Welsbach Company
Westinghouse Lamp Co.

INTERNAL COMBUSTION MOTORS

Duesenberg Motors Corporation
General Motors Corporation
Studebaker Corporation, The

IRON AND STEEL

American Rolling Mill Co., The
American Sheet and Tin Plate Co.
American Vanadium Company
Byers, A. M., Company
Carnegie Steel Company
Cleveland Testing Laboratory Co., The
Crane Co.
Holz & Company, Inc.
Inland Steel Company
Kokomo Steel and Wire Co.
Ludlum Steel Company
Metal & Thermit Corporation
Midvale Steel Company, The
Minneapolis Steel and Machinery Co.
National Tube Company
Pfaudler Co., The
United Alloy Steel Corporation

LEATHER AND GLUE

American Leather Research Laboratory
Armour Glue Works
Brunswick-Balke-Collender Co., The
Cudahy Packing Company, The
Gallun, A. F., & Sons Co.
Kistler, Lesh & Company
Kullman, Salz & Co.
Morris & Company

Nichols Laboratories, The
Pantasote Leather Company, The
Pfister & Vogel Leather Co.
United States Glue Co.

LIGHT

American Optical Company
Ansco Company
Bausch & Lomb Optical Co.
Case Research Laboratory
Corning Glass Works
Eastman Kodak Company
Fry, H. C., Glass Company
Keuffel & Esser Co.
National Lamp Works of General Electric Co.
Spencer Lens Company

LIQUORS, FERMENTED AND DISTILLED

Schoenhofen, Peter, Brewing Company, The
Scott, Ernest, & Company
U. S. Industrial Alcohol Co.
Wahl-Henius Institute, Incorporated
Warner, William R., & Company, Incorporated

LUBRICANTS

Acheson Graphite Company
Gray Industrial Laboratories, The
Lockhart Laboratories
Martinez Refinery, Shell Co. of California
Pittsburgh Testing Laboratory
Standard Oil Company
Vacuum Oil Company

MACHINE TOOLS

Brown & Sharpe M'f'g Co.
Chandler Engineering Corporation
Industrial Research Corporation
United Shoe Machinery Corporation

MARINE ENGINEERING

Bethlehem Shipbuilding Corporation, Ltd.
Cramp, William, & Sons Ship & Engine Building Co., The

MECHANICS, GENERAL

Chandler Engineering Corporation
Lumen Bearing Company

METAL MANUFACTURES, MISCELLANEOUS

American Vanadium Company
Crane Co.

METALLURGY AND METALLOGRAPHY

Aluminum Castings Co., The
American Brass Company, The
American Optical Company
American Rolling Mill Co., The
American Sheet and Tin Plate Co.
American Vanadium Company
Anaconda Copper Mining Co.
Bennett's Chemical Laboratory
Bridgeport Brass Company
Buffalo Foundry and Machine Co.
Byers, A. M., Company
Carnegie Steel Company
Cleveland Testing Laboratory Co., The
Crane Co.
Dorr Company, The
Electro-Metallurgical Company
General Electric Company
Guggenheim Bros.
Holz & Company, Inc.
International Nickel Co., The
Kalmus, Comstock & Westcott, Inc.
Kokomo Steel and Wire Co.
Lunkenheimer Co., The
Maynard, T. Poole
Metal & Thermit Corporation
Midvale Steel Company, The
Page, Carl M.
Raritan Copper Works
Scovill Manufacturing Company
Souther, Henry, Engineering Co., The
Stewart-Warner Speedometer Corporation
Stone & Webster
Titanium Alloy Manufacturing Company, The
United Alloy Steel Corporation
United States Metals Refining Co.

MILITARY AND NAVAL EQUIPMENT

Remington Arms, United Metallic Cartridge Company
Winchester Repeating Arms Co.

NON-FERROUS METALS (Aluminum)

Aluminum Castings Co., The

NON-FERROUS METALS (Copper)
Anaconda Copper Mining Co.
Phelps Dodge Corporation
Raritan Copper Works

NON-FERROUS METALS
American Brass Company, The
American Sheet and Tin Plate Co.
American Vanadium Company
American Zinc, Lead and Smelting Company
Bridgeport Brass Company
Chase Metal Works
Crane Co.
Cramp, William & Sons Ship & Engine Building Co., The
Gurley, W. & L. E.
Hoskins Manufacturing Company
International Nickel Co., The
International Silver Company
Metal & Thermit Corporation
National Lead Company
New Jersey Zinc Company, The
Scovill Manufacturing Company
Titanium Alloy Manufacturing Company, The
United States Metals Refining Co.

PAINTS, VARNISHES AND RESINS
Babcock Testing Laboratory
Berry Bros., Inc.
Cabot, Samuel, Inc.
du Pont, E. I., de Nemours & Company
Glidden Company, The
Industrial Research Laboratories
Krebs Pigment and Chemical Co., The
National Lead Company
Newport Turpentine & Rosin Company of Florida
Patton Paint Company
Redmanol Chemical Products Co.
Sears, Roebuck and Co.
Toch Brothers
Westinghouse Church Kerr & Co., Incorporated

PETROLEUM, ASPHALT AND WOOD PRODUCTS
Atlantic Refining Company, The
Empire Companies, The
Florida Wood Products Co.
Gulf Pipe Line Company
Institute of Industrial Research, The
Krebs Pigment and Chemical Co., The
Lockhart Laboratories
Martinez Refinery, Shell Co. of California
Medina Gas & Fuel Co.
Standard Oil Company
Vacuum Oil Company

PHOTOGRAPHY
Ansco Company
Eastman Kodak Company
Kalmus, Comstock & Westcott, Inc.

PROPERTIES OF ENGINEERING MATERIALS
Carnegie Steel Company
Chandler Engineering Corporation
Duesenberg Motors Corporation
General Electric Company
Institute of Industrial Research, The
Kokomo Steel and Wire Co.
Mellon Institute of Industrial Research
Pennsylvania Railroad Company, The
Scovill Manufacturing Company
Stewart-Warner Speedometer Corporation
Stone & Webster
Structural Materials Research Laboratory, Lewis Institute
United Shoe Machinery Corporation

PULVERIZING
Abbé Engineering Company
Philadelphia Quartz Company

RAILROAD ROLLING-STOCK AND ACCESSORIES
Baldwin Locomotive Works, The
Industrial Works
Pennsylvania Railroad Company, The

RAILROAD TRACK AND SIGNALS
Pennsylvania Railroad Company, The
Union Switch & Signal Company

RUBBER AND ALLIED SUBSTANCES
Belden Manufacturing Company
Boonton Rubber Manufacturing Company
Brunswick-Balke-Collender Co., The
Falls Rubber Company, The
Firestone Tire & Rubber Company
Fisk Rubber Company, The

General Bakelite Company
General Tire & Rubber Co.
Goodrich, B. F., Company, The
Goodyear Tire & Rubber Company, The
Hood Rubber Company
Krebs Pigment and Chemical Co., The
Manhattan Rubber Mfg. Co., The
Miller Rubber Co., The
Portage Rubber Co., The
Rubber Trade Laboratory

SOILS AND FERTILIZERS

American Agricultural Chemical Company, The
American Cyanamid Company
Cudahy Packing Company, The
Morris & Company
Royster, F. S., Guano Company

STEAM POWER

Babcock & Wilcox Co., The
Harrison Safety Boiler Works

SUGAR

American Beet Sugar Company
American Sugar Refining Company, The
Arbuckle Brothers
Digestive Ferments Company
Great Western Sugar Company, The
Spreckels Sugar Company
Western Sugar Refinery

TEXTILE MANUFACTURE AND CLOTHING

Amoskeag Manufacturing Company
Arlington Mills
Bloede, Victor G., Co.
Emerson Laboratory
Sears, Roebuck and Co.
U. S. Conditioning and Testing Co.

WATER, SEWAGE AND SANITATION

Dearborn Chemical Company
Dorr Company, The
Harrison Safety Boiler Works
Lederle Laboratories
Permutit Company, The
Souther, Henry, Engineering Co., The
Weston & Sampson

WELDING

Davis-Bournonville Company
Metal & Thermit Corporation

Commercial Classification of Laboratories Connected with Industrial Establishments

NOTE.—In this list the laboratories are grouped under selected trade designations in common use. The number of classes has been kept small and provides only for the laboratories, concerning which information has been obtained. It can, however, readily be extended.

1. ABRASIVES AND GRINDING
   Armour Sand Paper Works
   Carborundum Company, The
   Norton Company

2. ADHESIVES (Glue, Paste, Gum, Sizing, etc.)
   Armour Glue Works
   Bloede, Victor G., Co.
   Brunswick-Balke-Collender Co., The
   National Gum & Mica Co.
   United States Glue Co.

3. AIRCRAFT (Airplanes, Balloons, Dirigibles; Accessories)
   Chandler Engineering Corporation
   Curtiss Engineering Corporation, The
   Martin, Glenn L., Company, The

4. APPARATUS AND INSTRUMENTS (Astronomical, Chemical, Physical, Surveying, etc.)
   Bausch & Lomb Optical Co.
   Buffalo Foundry and Machine Co.
   Central Scientific Company
   Chandler Engineering Corporation
   Eimer & Amend
   Gurley, W. & L. E.
   Holz & Company, Inc.
   Keuffel & Esser Co.

Scientific Instrument and Electrical Machine Company, The
Waltham Watch Company

5. AUTOMOBILES AND ACCESSORIES
Duesenberg Motors Corporation
Firestone Tire & Rubber Company
General Motors Corporation
Northwestern Chemical Co., The
Packard Motor Car Company
Prest-O-Lite Co., Inc., The
Stewart-Warner Speedometer Corporation
Studebaker Corporation, The

6. BEVERAGES (Beers, Wines, Liquors, and Non-Alcoholic Drinks)
Dehls & Stein, Inc.
Nowak Chemical Laboratories
Schoenhofen, Peter, Brewing Company, The
Wahl-Henius Institute, Incorporated

7. BIOLOGICAL EQUIPMENT AND SUPPLIES
Digestive Ferments Company
Lilly, Eli, and Company
Mulford, H. K., Company

8. BOOTS AND SHOES (Including Machinery)
United Shoe Machinery Corporation

9. BRASS, BRONZE, BEARING METALS, COPPER
American Brass Company, The
Anaconda Copper Mining Co.
Bridgeport Brass Company
Chase Metal Works
Cramp, William, & Sons Ship & Engine Building Co., The
Lumen Bearing Company
Phelps Dodge Corporation
Raritan Copper Works
Remington Arms, United Metallic Cartridge Company
Scovill Manufacturing Company
United States Metals Refining Co.
Waltham Watch Company
Western Precipitation Company

10. BUILDING MATERIALS; CEMENT
Beaver Company, The
Pennsylvania Railroad Company, The
Structural Materials Research Laboratory, Lewis Institute
Westinghouse Church Kerr & Co., Incorporated

11. BY-PRODUCTS FROM WASTES
Babcock Testing Laboratories
Guggenheim Bros.
Scott, Ernest, & Company
Semet-Solvay Company
Vacuum Oil Company
Western Precipitation Company
Wilson & Co.

12. CANS AND OTHER METAL CONTAINERS
American Can Company
National Canners Association

13 CERAMICS (Bricks, Pottery, Refractories)
Buckeye Clay Pot Co.
Carborundum Company, The
Champion Ignition Co.
Corning Glass Works
Electro-Metallurgical Company
Harbison-Walker Refractories Company
Kraus Research Laboratories, Inc.
Laclede-Christy Clay Products Company
Pfaudler Co., The
Powers-Weightman-Rosengarten Company, The

14. CHEMICALS, FINE
Baker, J. T., Chemical Co.
Carus Chemical Company
Digestive Ferments Company
General Chemical Co.
Lindsay Light Company
Merck & Co.
Monsanto Chemical Works
Pennsylvania Salt Manufacturing Co.
Squibb, E. R., & Sons

15. CHEMICALS, HEAVY (Bulk, Acids, Salts, etc.)
Armour Ammonia Works

Davison Chemical Company
Drackett, P. W., & Sons Co., The
Du Pont, E. I., de Nemours & Company
General Chemical Co.
Hooker Electrochemical Co.
Kidde, Walter, & Company, Incorporated
Mathieson Alkali Works (Inc.), The
Merrimac Chemical Co.
Niagara Alkali Co.
Pennsylvania Salt Manufacturing Co.
Philadelphia Quartz Company
Powers - Weightman - Rosengarten Company, The
Roessler & Hasslacher Chemical Company, The
Semet-Solvay Company
Solvay Process Company, The
U. S. Industrial Alcohol Co.
Victor Chemical Works

16. COTTON AND ITS PRODUCTS
American Cotton Oil and Associated Cos.
Southern Cotton Oil Company, The

17. DIVERSIFIED MANUFACTURING
Brunswick-Balke-Collender Co., The
Larkin Co.
Sears, Roebuck and Co.

18. DRYERS, EVAPORATORS, SEPARATORS, CONCENTRATORS, FILTER PRESSES, GRINDING AND PULVERIZING MACHINERY
Abbé Engineering Company
Buffalo Foundry and Machine Co.
DeLaval Separator Co., The
Dorr Company, The
Sperry, D. R., & Co.
Tolhurst Machine Works
Western Precipitation Company

19. DYESTUFFS
Bloede, Victor G., Co.
Butterworth-Judson Corporation
Dehls & Stein, Inc.
Klipstein, E. C., & Sons Co.
Lindsay Light Company
MacAndrews & Forbes Company
Metz, H. A., Laboratories, Inc.
National Aniline & Chemical Company, Inc.
Peerless Color Company
Reliance Aniline & Chemical Co., Incorporated
U. S. Conditioning and Testing Co.
Western Aniline Products Company
Zinsser & Co.

20. ELECTRICAL EQUIPMENT (Dynamos, Motors, Lamps, Instruments, Telephones, Batteries; Light and Power Plants)
Commonwealth Edison Company
Cutler-Hammer Mfg. Co., The
Dayton Engineering Laboratories Co.
Detroit Edison Company, The
Edison, Thomas A., Laboratory
Electrical Testing Laboratories
Electro Chemical Company, The
General Electric Company
Hoskins Manufacturing Company
Kilbourne & Clark Manufacturing Company
Leeds & Northrup Company, The
Lincoln, E. S., Inc.
National Carbon Company, Inc.
National Lamp Works of General Electric Co.
Sangamo Electric Company
Western Electric Company, Incorporated
Westinghouse Electric & Manufacturing Company
Westinghouse Lamp Co.
Winchester Repeating Arms Co.

21. ENGINES AND MOTORS (other than electric)
Duesenberg Motors Corporation
General Motors Corporation

22. EXPLOSIVES
Aetna Explosives Company, Inc.
Atlas Powder Co.

du Pont, E. I., de Nemours & Company
Hercules Powder Company
Remington Arms, United Metallic Cartridge Company
Winchester Repeating Arms Co.

23. FERTILIZERS
American Agricultural Chemical Company, The
American Cyanamid Company
Royster, F. S., Guano Company

24. FIRE PREVENTION
Associated Factory Mutual Fire Insurance Companies
MacAndrews & Forbes Company
Underwriters' Laboratories

25. FOODSTUFFS (Including Candy, Baking Powder, Flavoring Extracts)
Arbuckle Bros.
Brach, E. J., and Sons
Corn Products Refining Company
Cudahy Packing Company, The
Howard Wheat and Flour Testing Laboratory, The
Marvin-Davis Laboratories, Incorporated
Merrell-Soule Laboratory
Mojonnier Bros. Co.
Morris & Company
Musher and Company, Incorporated
National Canners Association
Nestlé's Food Company, Incorporated
New England Confectionery Company
Nowak Chemical Laboratories
Redlands Fruit Products Company
Rumford Chemical Works
Sprague, Warner & Company
U. S. Food Products Corp.
Wahl-Henius Institute, Incorporated
Washburn-Crosby Co.
Wilson & Co.

26. FUELS (Coal, Charcoal, Coke, Gas, Oil, Peat, Wood, etc.)
Empire Companies, The
Koppers H., Company
Milwaukee Coke & Gas Company, The

27. GAS (Fuel and Illuminating) INCLUDING MANTLES
Linde Air Products Company
Medina Gas & Fuel Co.
Prest-O-Lite Co., Inc., The
Providence Gas Company
Standard Oil Company
United Gas Improvement Co., The
Welsbach Company

28. GASES (except fuel and illuminating), INCLUDING GENERATING APPARATUS
Burdett Manufacturing Company
Florida Wood Products Co.
Hooker Electrochemical Co.
Linde Air Products Company
Mathieson Alkali Works (Inc.), The

29. GLASS (Window, Plate, Table)
American Window Glass Co.
Corning Glass Works
Fry, H. C., Glass Company

30. GRAPHITE, CARBON and Their Products
Acheson Graphite Company
National Carbon Company, Inc.

31. HAIR (Curled, etc.)
Armour Curled Hair Works

32. INK (Printing and Writing; Ribbons)
Ault & Wiborg Company, The
Eagle Printing Ink Co., The
Morrill, Geo. H., Co.
Northwestern Chemical Co., The

33. INSULATED WIRE (Cable, Cordage and Accessories)
Belden Manufacturing Company

34. INSULATION (Electrical and Thermal)
Boonton Rubber Manufacturing Company
Champion Ignition Co.
Condensite Company of America
General Bakelite Company
Redmanol Chemical Products Co.

35. IRON (Wrought and Cast; Pipe)
    American Rolling Mill Co., The
    Byers, A. M., Company
    Electro-Metallurgical Company
    Metal & Thermit Corporation
    National Tube Company

36. LABORATORIES (Commercial, Research, Testing, etc.)
    Babcock Testing Laboratory
    Beckman and Linden Engineering Corporation
    Bennetts' Chemical Laboratory
    Boston Bio-Chemical Laboratory, (Inc.), The
    Case Research Laboratory
    Charlotte Chemical Laboratories, Inc.
    Cleveland Testing Laboratory Co., The
    Detroit Testing Laboratory, The
    Dorr Company, The
    Edison, Thomas A., Laboratory
    Electrical Testing Laboratories
    Ellis, Carleton, Laboratories
    Emerson Laboratory
    FitzGerald Laboratories, Inc., The
    Gray Industrial Laboratories, The
    Heinrich Laboratories of Applied Chemistry
    Hochstadter Laboratories
    Howard Wheat and Flour Testing Laboratory, The
    Industrial Research Corporation
    Industrial Research Laboratories
    Industrial Testing Laboratories
    Industrial Works
    Institute of Industrial Research, The
    Kalmus, Comstock & Westcott, Inc.
    Kidde, Walter, & Company, Incorporated
    Kraus Research Laboratories, Inc.
    Lederle Laboratories
    Lincoln, E. S., Inc.
    Little, Arthur D., Inc.
    Littlefield Laboratories Co.
    Lockhart Laboratories
    Maynard, T. Poole
    Mellon Institute of Industrial Research
    Metz, H. A., Laboratories, Inc.
    Nichols Laboratories, The
    Nowak Chemical Laboratories
    Page, Carl M.
    Pittsburgh Testing Laboratory
    Schwarz Laboratories
    Souther, Henry, Engineering Co., The
    Squibb, E. R., & Sons
    U. S. Conditioning and Testing Co.

37. LABORATORY SUPPLIES
    Eimer & Amend

38. LEAD
    See Zinc

39. LEATHER AND LEATHER GOODS (Tanning, etc.; substitutes)
    American Leather Research Laboratory
    Gallun, A. F., & Sons Co.
    Kistler, Lesh & Company
    Kullman, Salz & Co.
    Pantasote Leather Company, The
    Pfister & Vogel Leather Co.

40. LUBRICANTS Grease, Graphite, Oil)
    Acheson Graphite Company
    Standard Oil Company
    Vacuum Oil Company

41. MACHINE TOOLS
    Brown & Sharpe Mfg. Co.
    Industrial Research Corporation
    United Shoe Machinery Corporation

42. MATCHES
    Diamond Match Co., The

43. NON-FERROUS METALS, Miscellaneous
    Aluminum Castings Co., The
    American Vanadium Company
    Doehler Die-Casting Co.
    Guggenheim Bros.
    Hoskins Manufacturing Company
    International Nickel Co., The
    International Silver Company
    Metal & Thermit Corporation
    Titanium Alloy Manufacturing Company, The

44. OPTICAL GOODS
- American Optical Company
- Bausch & Lomb Optical Co.
- Corning Glass Works
- Spencer Lens Company

45. PAINTS, OILS, VARNISHES, LACQUERS
- Berry Bros., Inc.
- Cabot, Samuel, Inc.
- Condensite Company of America
- du Pont, E. I., de Nemours & Co.
- Glidden Company, The
- Krebs Pigment and Chemical Co.,
- National Lead Company
- Newport Turpentine & Rosin Company of Florida
- Patton Paint Company
- Redmanol Chemical Products Co.
- Toch Brothers

46. PAPER AND PULP
- American Writing Paper Co.
- Brown Company (formerly Berlin Mills Company)
- Crane & Co.
- Cumberland Mills (S. D. Warren & Co.)
- Dill & Collins Co.
- du Pont, E. I., de Nemours & Company
- Eastern Manufacturing Company
- Hamersley M'f'g Co.
- Remington Arms, United Metallic Cartridge Company
- Strathmore Paper Company
- Weston, Byron, Co.

47. PETROLEUM AND ITS PRODUCTS
- Atlantic Refining Company, The
- Cosden & Company
- Ellis, Carleton, Laboratories
- Empire Companies, The
- Empire Gasoline Company
- Gray Industrial Laboratories, The
- Gulf Pipe Line Company
- Martinez Refinery, Shell Co. of California
- Standard Oil Company
- Vacuum Oil Company

48. PHARMACEUTICAL PREPARATIONS (Drugs, Patent Medicines, etc.)
- American Research Fund
- Cudahy Packing Company, The
- Kolynos Co., The
- Lilly, Eli, and Company
- Merck & Co.
- Parke, Davis & Company
- Squibb, E. R., & Sons
- United Drug Co.
- Upjohn Company, The
- Warner, William R., & Company, Incorporated
- Zinsser & Co.

49. PHONOGRAPHS AND GRAPHOPHONES
- Columbia Graphophone Manufacturing Company
- Edison, Thomas A., Laboratory

50. PHOTOGRAPHIC EQUIPMENT (Cameras, Films, Plates, etc.)
- Ansco Company
- Eastman Kodak Company

51. PIPE (Iron and Steel) and FITTINGS
- Byers, A. M., Company
- Crane Co.
- Lunkenheimer Co., The
- National Tube Company

52. PLASTICS
- Columbia Graphophone Manufacturing Company
- Condensite Company of America
- du Pont, E. I., de Nemours & Company
- General Bakelite Company
- Redmanol Chemical Products Co.

53. PUBLIC UTILITIES
- Stone & Webster
- Westinghouse Church Kerr & Co., Incorporated

54. RADIO EQUIPMENT (Wireless, Telegraph, Telephone)
- American Radio and Research Corporation
- Kilbourne & Clark Manufacturing Company

55. RAILROADS
- Pennsylvania Railroad Company, The

56. RAILROAD EQUIPMENT (other than Rolling-Stock)
   Union Switch & Signal Company

57. RAILROAD ROLLING-STOCK (Cars, Locomotives and Accessories)
   Baldwin Locomotive Works, The

58. RUBBER AND RUBBER GOODS and Substitutes
   Boonton Rubber Manufacturing Company
   Brunswick-Balke-Collender Co., The
   Condensite Company of America
   Falls Rubber Company, The
   Firestone Tire & Rubber Company
   Fisk Rubber Company, The
   General Bakelite Company
   General Tire & Rubber Co.
   Goodrich, B. F., Company, The
   Goodyear Tire & Rubber Company, The
   Hood Rubber Company
   Manhattan Rubber Mfg. Co., The
   Miller Rubber Co., The
   Portage Rubber Co., The
   Rubber Trade Laboratory

59. SANITATION, SANITARY EQUIPMENT AND SUPPLIES
   Lederle Laboratories
   Souther, Henry, Engineering Co., The
   Weston & Sampson

60. SHIPBUILDING
   Bethlehem Shipbuilding Corporation, Ltd.
   Cramp, William & Sons Ship & Engine Building Co., The

61. SOAP
   Armour Soap Works
   Globe Soap Co.
   Larkin Co.

62. STEAM BOILERS AND ACCESSORIES
   Babcock & Wilcox Co., The
   Dearborn Chemical Company
   Harrison Safety Boiler Works

63. STEEL MILLS
   Carnegie Steel Company
   Inland Steel Company
   Kokomo Steel and Wire Co.
   Ludlum Steel Company
   Midvale Steel Company, The
   Minneapolis Steel and Machinery Co.
   United Alloy Steel Corporation

64. SUGAR
   American Beet Sugar Company
   American Sugar Refining Company, The
   Arbuckle Brothers
   Great Western Sugar Company, The
   Spreckels Sugar Company
   Western Sugar Refinery

65. TAR and Its Products
   Barrett Company, The
   Cabot, Samuel, Inc.

66. TEXTILES AND CLOTHING
   Amoskeag Manufacturing Company
   Arlington Mills
   Art in Buttons
   Stevens, M. T., & Sons Co.
   U. S. Conditioning and Testing Co.

67. TIN PLATE
   American Can Company
   American Sheet and Tin Plate Co.

68. WATER TREATMENT
   Permutit Company, The
   Weston & Sampson

69. WELDING (Electric, Forge, Gas)
   Davis-Bournonville Company
   Metal & Thermit Corporation

70. WIRE
   Kokomo Steel and Wire Co.

71. WOOD and its Products
   Florida Wood Products Co.

72. ZINC AND LEAD
   American Zinc, Lead and Smelting Company
   National Lead Company
   New Jersey Zinc Company, The
   Stone & Webster
   Western Precipitation Company

Cross-references

Bulletin of the National Research Council

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Number 7. The larger opportunities for research on the relations of solar and terrestrial radiation. By C. G. Abbot. Pages 13. Price 20 cents.

Vol. 1. Part 3 JUNE, 1920 Number 3

BULLETIN
OF THE
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PERIODICAL BIBLIOGRAPHIES AND ABSTRACTS FOR THE SCIENTIFIC AND TECHNOLOGICAL JOURNALS OF THE WORLD

Compiled by RUTH COBB
National Research Council

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Vol. 1, Part 3 JUNE 1920 Number 3

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CONTENTS

INTRODUCTION

This publication is the preliminary edition of a list of scientific and technological bibliographies, abstract journals and systematic yearbooks which appear at more or less regular intervals. It has been the intention to include all serials which systematically and comprehensively index, abstract or summarize literature of the various branches of science.

The arrangement of the information concerning each serial is as follows: title, subtitle, quotation of heading under which index or abstracts occur (in journals which also publish original materials), location and name of publisher, frequency of publication, volume number and date of last issue received. The name of

one or more of the scientific libraries of Washington in which the serial may be found is also given, but there has been no attempt to locate *all* of the sets of each serial available in this city.

This list is intended to contain only current material, but in cases where it is uncertain whether or not a publication interrupted by the war will be continued, the name has been included.

It is planned to amplify the list by indicating for each serial its scope, classification and arrangement. Corrections and additions will be welcomed so that a succeeding edition may be more nearly complete.

AGRICULTURE AND FORESTRY

Bibliographies

Agricultural index. White Plains, N. Y., Wilson. Monthly except August and December. 5v, 1920. Agr. LC.

American forestry. "Current literature." American Forestry Association, Washington. Monthly. 26v, 1920. Agr.

Bulletin de l'Association de Documentation Bibliographique, Scientifique, Industrielle et Commerciale. Paris. Quarterly. 9v, 1919. Agr.

Index of books, periodicals and newspapers on rural economy. Petrograd, Kirschbaum. Annual. 27v, 1911 (in 1915). (Published in Russian; title given is a translation.) Agr.

Oversigt over fremmed litteratur; vedrorende landbrugets jorddyrkning og plantekultur. Copenhagen, Christensen. Annual. 24v, 1915. Agr.

Phytopathology. "Literature on plant diseases." Official organ of the American Phytopathological Society. Baltimore. Monthly. 10v, 1920. Agr.

Abstracts and Systematic Yearbooks

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Experiment station record. U. S. Department of Agriculture, Washington. Monthly with bimonthly abstract numbers. 42v, 1920. Agr. GS. LC. Pat. Sm.

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Jahrbuch der moorkunde. Bericht über die fortschritte auf allen gebieten der moorkultur und torfverwertung. Hannover, M. and H. Schaper. Annual. 1-v, 1912. Agr.

Jahrbuch für wissenschaftliche und praktische tierzucht, einschliesslich der züchtungsbiologie. Hannover, M. and H. Schaper. Annual. 9v, 1914. Agr.

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ANTHROPOLOGY

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L'Anthropologie. (Bulletin bibliographique.) Paris, Masson. Bimonthly. 29v, 1918–1919. Eth. GS. Sm. Surg.

Bibliographie anatomique; revue des travaux en langue française. Paris Berger-Levrault. Appears irregularly. 25v, 1914. LC. Sm. Surg.

Bibliographie der deutschen naturwissenschaftlichen literatur. Herausgegeben im Auftrage des Reichsamtes des Innern vom deutschen Bureau der internationalen Bibliographie in Berlin. Berlin, Heymann. Appears irregularly. 18v, 1914. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

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Index catalogue of the library of the surgeon-general's office. U. S. Army Washington, Government Printing Office. Annual. Third series, 1-v, 1916. LC. Surg.

Index medicus. A monthly classified record of the current medical literature of the world. (Replaces bibliographia medica. Recueil mensuel. Classement methodique de la bibliographie internationale des sciences medicales. Paris, Institut de Bibliographie. 3v, 1903.) The Carnegie Institution of Washington. Monthly. Second series, 18v, 1920. Agr. LC. Surg.

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Naturae novitates. Bibliographie neuer erscheinungen aller länder auf dem gebiete der naturgeschichte und der exacten wissenschaften. Berlin, Friedländer & Sohn. Bimonthly. 41v, 1919. Agr. GS. LC. Sm.

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Abstracts and Systematic Yearbooks

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Beiblätter zu den annalen der physik. Leipzig, Barth. Semimonthly. 43v, 1919. Agr. GS. LC. Obs. Pat. Sm. St.

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Die Fortschritte der physik. Braunschweig, Vieweg & Sohn. Annual. 73v, 1917. GS. LC. Pat. Sm. St.

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See also Bacteriology, Physiology and Agriculture

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See also Engineering and Industry

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See also Bacteriology and Physiology

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Pharmaceutisch weekblad. "Referaten." Amsterdam, Centen. Weekly. 57v, 1920. Agr.

The Review of applied entomology. Series A, agriculture. Series B, medical and veterinary. London, Imperial Bureau of Entomology. Monthly. 8v, 1920. Agr.

Review of neurology and psychiatry. Edinburgh and London, Foulis. Monthly. 16v, 1918. Surg.

Schmidts jahrbücher der in- und ausländischen gesamten medizin. Bonn, Marcus & Webers. Monthly. 329v, 1919 (324–326v, incomplete). Surg.

Strahlentherapie. Mitteilungen aus dem gebiete der behandlung mit röntgenstrahlen, licht und radioaktiven substanzen zugleich zentralorgan für krebs- und lupusbe handlung. "Referate." Berlin and Vienna, Urban und Schwarzenberg. Irregular. 1-v, 1914. Surg.

Veröffentlichungen aus den jahres-veterinär-berichten der beamteten tierärzte preussens. Berlin, Parey. Annual. 12v, 1911 (in 1913). Agr. Surg.

Zeitschrift für die gesamte neurologie und psychiatrie. "Referate." Berlin, Springer. Semimonthly. 17v, 1918. Surg.

Zeitschrift für tuberkulose. "Referate." Leipzig, Barth. Monthly. 29v, 1918. Agr. Surg.

Zentralblatt für chirurgie. Leipzig, Barth. Weekly. 47v, 1920. Surg.

Zentralblatt für chirurgische und mechanische orthopädie. "Literatur." Berlin, Karger. Monthly. 13v, 1919. Surg.

Zentralblatt für die gesamte gynaekologie und geburtshilfe sowie deren grenzgebiete. "Referate." Berlin, Springer. 16 to 18 numbers a year. 5v, 1914. Surg.

Zentralblatt für die gesamte landwirtschaft mit einschluss der forst- und teichwirtschaft, der tier-pathologie und -medizin. Leipzig, Borntraeger. Monthly. 1-v, 1920. Agr.

Zentralblatt für die gesamte ophthalmologie und ihre grenzgebiete. "Referate." Berlin, Springer. Monthly. 2v, 1914. Surg.

Zentralblatt für die gesamte therapie. "Referate." Berlin, Coblentz. Monthly. 35v, 1917. Surg.

Zentralblatt für gynäkologie. Leipzig, Barth. Weekly. 44v, 1920. Surg.

Zentralblatt für herz-u. gefässkrankheiten. "Referate." Leipzig, Steinkopff. Bimonthly. 12v, 1920. Surg.

Zentralblatt für innere medizin. Leipzig, Barth. Weekly. 41v, 1920. Surg.

Zentralblatt für kinderheilkunde. "Referate." Leipzig, Barth. Monthly. 22v, 1917. Surg.

Zentralblatt für normale anatomie und mikrotechnik. Berlin, Urban & Schwarzenberg. Monthly. 11v, 1914. Surg.

Zentralblatt für röntgenstrahlen, radium und verwandte gebiete. "Referate." Wiesbaden, Bergmann. Monthly. 9v, 1918. Surg.

PHYSICS

Bibliographies

Bibliographie der deutschen naturwissenschaftlichen literatur. Herausgegeben im Auftrage des Reichsamtes des Innern vom deutschen Bureau der Internationalen Bibliographie in Berlin. Berlin, Heymann. Appears irregularly. 18v, 1914. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

Bibliographie scientifique française, recueil mensuel, publie sous les auspices du Ministère du l'Instruction publique par le Bureau Française du Catalogue International de Littérature Scientifique. Paris, Gauthier-Villars. Monthly. 15v, 1918. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

Halbmonatliches literatur verzeichnis der "Fortschritte der physik" Dargestellt von der Deutschen Physikalischen Gesellschaft. Braunschweig, Vieweg & Sohn. Semimonthly. 17v, 1918. St.

International catalogue of scientific literature. C, physics. Continuation of Catalogue of scientific papers. The Royal Society of London. London, Harrison. Annual. 14v, 1914 (in 1917). Agr. GS. LC. St.

Naturae novitates. Bibliographie neuer erscheinungen aller länder auf dem gebiete der naturgeschichte und der exacten wissenschaften. Berlin, Friedländer & Sohn. Bimonthly. 41v, 1919. Agr. GS. LC. Sm.

Zeitschrift für Mathematik und Physik. Organ für angewandte Mathematik. Leipzig, Teubner. 64v, 1916. Obs.

Abstracts and Systematic Yearbooks

Beiblätter zu den annalen der physik. Leipzig, Barth. Semimonthly. 43v, 1919. Agr. GS. LC. Obs.

Die Fortschritte der physik. Braunschweig, Vieweg & Sohn. Annual. 73v, 1917. GS. LC. Pat. Sm. St.

Jahrbuch der radioaktivität und elektronik. Leipzig, Hirzel. Annual, 15v, 1918–1919 (14v lacking). LC. St.

Journal de physique théorique et appliquée. Paris, Guillet. Monthly. 7v, 1917. GS. LC. Obs. Pat. St.

Science abstracts. A, physics; B, electrical engineering. London, Spon. Monthly. 23v, 1920. Agr. LC. Pat. Sm. St.

PHYSIOLOGY

Bibliographies

Bibliographia physiologica (diario zentralblatt für physiologie adnexa), edidit Concilium Bibliographicum. Leipzig, Deuticke. Quarterly. Third series, 9v, 1913. Agr.

Bibliographie der deutschen naturwissenschaftlichen literatur. Herausgegeben im Auftrage des Reichsamtes des Innern vom deutschen Bureau der internationalen Bibliographie in Berlin. Berlin, Heymann. Appears irregularly. 18v, 1914. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

Bibliographie scientifique française, recueil mensuel, publie sous les auspices du Ministère de l'Instruction publique par le Bureau Française du Catalogue International de Littérature Scientifique. Paris, Gauthier-

Villars. Monthly. 15v, 1918. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

Concilium Bibliographicum. Zürich, Field. Card index. LC. Sm.

Index catalogue of the library of the surgeon-general's office, U. S. Army. Washington, Government Printing Office. Annual. Third series, 1-v, 1916. LC. Surg.

Index medicus. A monthly classified record of the current medical literature of the world. (Replaces bibliographia medica. Recueil mensuel. Classement methodique de la bibliographie internationale des sciences medicales. Paris, Institut de Bibliographie. 3v, 1903.) The Carnegie Institution of Washington. Monthly. Second series, 18v, 1920. Agr. LC. Surg.

International catalogue of scientific literature. Q, physiology. Continuation of Catalogue of scientific papers. The Royal Society of London. London, Harrison. Annual. 12v, 1912 (in 1917). Agr. LC.

Zeitschrift für psychologie und physiologie der sinnesorgane. "Bibliographie der deutschen und ausländischen literatur über psychologie, ihre hilfswissenschaften und grenzgebiete." Leipzig, Barth. Annual. 81v, 1919 (74v–79v, incomplete). LC. Sm. Surg.

Abstracts and Systematic Yearbooks

Botanical abstracts. Baltimore, Williams & Wilkins. Monthly. 3v, 1920. Agr. GS. LC.

Botanisches centralblatt. Referierendes organ der Association Internationale des Botanistes für das Gesamtgebiet der Botanik. Jena, Fischer. 26 numbers a year. 141v, 1920 (1916–1917 incomplete). Agr.

Bulletin de l'Institut Pasteur. Revues et analyses des travaux de bactériologie, médicine, biologie générale, physiologie, chimie biologique dans leurs rapports avec la microbiologie. Paris, Masson et Cie. Semimonthly. 17v, 1919. Agr. Surg.

Jahresberichte über die fortschritte der anatomie und entwicklungsgeschichte. Jena, Fischer. Annual. New series, 19v, 1913 (in 1915). LC. Surg.

Jahres-bericht über die fortschritte der tierchemie, oder der physiologischen pathologischen und immuno-chemie und der pharmakologie. Wiesbaden, Bergmann. Annual. 44v, 1914. Agr. Pat.

Physiological abstracts, issued by the Physiological Society (Great Britain and Ireland). London, Lewis & Co. Monthly. 4v, 1920. Agr.

The Review of bacteriology, protozoology and general parasitology; an

epitome of general parasitology, bacteriology and allied subjects in their relationship to pathology and hygiene. London, Science Reviews, Ltd. Bimonthly. 9v, 1919. Agr.

Zeitschrift für gärungsphysiologie allgemeine, landwirtschaftliche und technische mykologie. Berlin, Borntraeger. Bimonthly. 5v, 1915. Agr.

Zeitschrift für psychologie und physiologie der sinnesorgane. "Bibliographie der deutschen und ausländischen literatur über psychologie, ihre hilfswissenschaften und grenzgebiete." Leipzig, Barth. 3–4 volumes, 6 parts each, annually. 81v, 1919 (74v–79v, incomplete). LC.

Zentralblatt für biochemie und biophysik, mit einschluss der theoretischen immunitätsforschung. Leipzig, Borntraeger. Semi-monthly. 21v, 1920 (19v, incomplete). Agr.

Zentralblatt für physiologie. Organ der Deutschen Physiologischen Gesellschaft unter Mitwirkung der Physiologischen Gesellschaft zu Berlin und der Morphologisch-physiologischen Gesellschaft zu Wien. Leipzig, Deuticke. Semimonthly. 34v, 1919 (32v, lacking). Agr. Surg.

PSYCHOLOGY

Bibliographies

Bibliographie der deutschen naturwissenschaftlichen literatur. Herausgegeben im Auftrage des Reichsamtes des Innern vom deutschen Bureau der internationalen Bibliographie in Berlin. Berlin, Heymann. Appears irregularly. 18v, 1914. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

Bulletin de la Société française de Philosophie. Section 8, Bibliographie de la philosophie française. Paris, Colin. Annual. LC.

Index catalogue of the library of the surgeon-general's office, U. S. Army. Washington, Government Printing Office. Annual. Third series, 1-v, 1916. LC. Surg.

Index medicus. (Replaces bibliographia medica. Recueil mensuel. Classement methodique de la bibliographie internationale des sciences medicales. Paris, Institut de Bibliographie. 3v, 1903.) A monthly classified record of the current medical literature of the world. The Carnegie Institution of Washington. Monthly. Second series, 18v, 1920. Agr. LC. Surg.

International catalogue of scientific literature. Q, physiology (including experimental psychology). Continuation of Catalogue of scientific papers. The Royal Society of London. London, Harrison. Annual. 12v, 1912 (in 1917). Agr. LC.

Die Philosophie der gegenwart; eine internationale jahresübersicht. Section II. Heidelberg, Weiss. Annual. 5v, 1916. LC.

Psychological index. Lancaster, Psychological Review Co. Annual. 24v, 1917. LC.

Zeitschrift für psychologie und physiologie der sinnesorgane. "Bibliographie der deutschen und ausländischen literatur über psychologie, ihre hilfswissenschaften und grenzgebiete." Leipzig, Barth. Annual. 81v, 1919 (74v–79v, incomplete). Surg.

Abstracts and Systematic Yearbooks

L'Année pedagogique. Paris, Alcan. Annual. 3v, 1913. LC.

L'Année psychologique. Paris, Masson et Cie. Annual. 20v, 1914. LC. Surg.

Review of neurology and psychiatry. Edinburgh and London, Foulis. Monthly. 16v, 1918. Surg.

Zeitschrift für die gesamte neurologie und psychiatrie. "Referate." Berlin, Springer. Semimonthly. 17v, 1918. Surg.

Zeitschrift für psychologie und physiologie der sinnesorgane. "Bibliographie der deutschen und ausländischen literatur über psychologie, ihre hilfswissenschaften und grenzgebiete." Leipzig, Barth. Annual. 81v, 1919 (74v–79v, incomplete). LC. Sm. Surg.

ZOOLOGY

See also Physiology and Medical Sciences

Bibliographies

Anatomischer anzeiger. Centralblatt für die gesamte wissenschaftliche anatomie, amtliches organ der Anatomischen Gesellschaft. "Annual list of literature." Jena, Fischer. 52v, 1919 (49v–50v, incomplete). Agr. Sm. Surg.

The Auk. "Recent Literature." The American Ornithologists' Union, Cambridge. Quarterly. 37v, 1920. Agr. GS. LC. Sm.

Bibliographia zoologica (adhuc diario "zoologischer anzeiger" adnexa). Zürich, Field. Concilium Bibliographicum. Annual. 29v, 1916. Ag. LC.

Bibliographie anatomique; revue des travaux en langue française. Paris, Berger-Levrault. Appears irregularly. 25v, 1914. LC. Sm. Surg.

Bibliographie der deutschen naturwissenschaftlichen literatur. Herausgegeben im Auftrage des Reichsamtes des Innern vom deutschen Bureau der internationalen Bibliographie in Berlin. Berlin, Heymann. Appears irregularly. 18v, 1914. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

Bibliographie scientifique française, recueil mensuel, publie sous les auspices du Ministère du l'Instruction publique par le Bureau Française

du Catalogue International de Littérature Scientifique. Paris, Gauthier-Villars. Monthly. 15v, 1918. Yearly cumulation published in the International catalogue of scientific literature. Agr. GS. LC.

Concilium Bibliographicum. Zürich, Field. Card index. LC. Sm.

Index to the literature of American economic entomology. American Association of Economic Entomologists. Melrose Highlands, Mass. Appears irregularly. Agr.

International catalogue of scientific literature. N, zoology, O, anatomy. Continuation of Catalogue of scientific papers. The Royal Society of London. London, Harrison. Annual. 14v, 1914 (in 1916). Agr. LC.

Naturae novitates. Bibliographie neuer erscheinungen aller länder auf dem gebiete der naturgeschichte und der exacten wissenschaften. Berlin, Friedländer & Sohn. Bimonthly. '41v, 1919. Agr. GS. LC. Sm.

Zoological Record (International catalogue of scientific literature). The Royal Society of London. London, Harrison. Annual. 54v, 1917 (in 1919). Agr. GS. LC.

Abstracts and Systematic Yearbooks

L'Annêe biologique. Paris, Delage. Annual. 21v, 1916. Agr. Surg.

Archiv für naturgeschichte. Berlin, Nicolaische Verlags-Buchhandlung, R. Stricker. Monthly. 83v, 1919. Agr. Sm.

Bibliographia evolutionis, du Bulletin biologique de la France et de la Belgique. Irregular. 5v, 1914. Agr.

Botanical abstracts. (Includes animal genetics.) Baltimore, Williams & Wilkins. Monthly. 3v, 1920. Agr. GS. LC.

Ergebnisse der zoologie. Jena, Fischer. 4v, 1913.

Jahresbericht über die fischereiliteratur. Neudamm, J. Neumann. Annual. 2v, 1912.

Jahresberichte über die fortschritte der anatomie und entwicklungsgeschichte. Jena, Fischer. Annual. New series, 19v, 1913 (in 1915). LC. Surg.

The Review of applied entomology. Series A, Agriculture. Series B, Medical and veterinary. London. Imperial Bureau of Entomology. Monthly. 8v, 1920. Agr.

Zentralblatt für normale anatomie und mikrotechnik. Berlin, Urban und Schwartzenberg. 11v, 1914. Surg.

Zentralblatt für zoologie allgemeine und experimentelle biologie. Successor to Zoologisches centralblatt. Berlin, Tuebner. Monthly. 6v, 1915–1916.

Zoologischer jahresbericht herausgegeben von der zoologischen station

zu Neapel. Berlin, Friedländer & Sohn. Annual. 37v, 1915. Agr. LC. Surg.

LIST OF ABBREVIATIONS

Agr....................Department of Agriculture
Eth....................Bureau of American Ethnology
GS....................Geological Survey
LC....................Library of Congress
Obs....................Naval Observatory
Pat....................Patent Office
Sm....................Smithsonian Institution
St....................Bureau of Standards
Surg....................War Department, Surgeon-General's Office

Bulletin of the National Research Council

Volume 1

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Number 9. A reading list on scientific and industrial research and the service of the chemist to industry. By Clarence Jay West. Pages 44. Price 50 cents.

Number 10. Report on the organization of the International Astronomical Union. Presented for the American Section, International Astronomical Union, by W. W. Campbell, Chairman, and Joel Stebbins, Secretary. (In press.)

Vol. 1. Part 4 AUGUST, 1920 Number 4

BULLETIN OF THE NATIONAL RESEARCH COUNCIL

NORTH AMERICAN FOREST RESEARCH

Investigative Projects in Forestry and Allied Subjects Conducted by National, State, and Provincial Governments, Schools of Forestry, Scientific Schools, and Private Interests in Canada, Newfoundland, and the United States for 1919–1920

Compiled by the Committee on American Forest Research, Society of American Foresters

Earle H. Clapp, Chairman, Clyde Leavitt, Walter Mulford
J. W. Toumey, E. A. Ziegler

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1920

Announcement Concerning Publications
of the
National Research Council

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CONTENTS

INTRODUCTION

Although forest research in North America is still very young, some distinct advance has already been made. Twenty years ago there were no foresters trained in American schools. To-day there are approximately 1500 trained foresters, graduates of technical schools of high standing, many of whom are devoting their efforts to forest research. The beginning of systematic forest research dates from the establishment of the Forest Products Laboratory at Madison, Wis., in 1909, of the Forest Products Laboratories of Canada at Montreal in 1915, and of the several forest experiment stations on the National Forests of the West, the first of which was established at Flagstaff, Arizona, in 1908.

Since this beginning, the increase in the number of agencies engaged in forest research and in the scope and intensity of the studies undertaken has been a promising indication of the growing need for adequate information along these lines. Not including the Federal departments of Canada, Newfoundland, and the United States, there are now from 40 to 50 state, provincial, college, and corporate organizations, and individuals engaged in the study of problems in forestry and related subjects.

Some 520 projects are now being conducted by various agencies in the United States, Canada, and Newfoundland. In view of the volume of work now being carried on, the Research Committee of the Society of American Foresters felt the need for some clearing-house of information on the current investigative projects. This program represents, therefore, an attempt to bring together the projects on which forest investigators are engaged in North America. It is hoped that it may be a means of informing the different investigators of the work of each other and in this way help indirectly to avoid duplication of effort and give the encouragement that must come from the knowledge that there are others who are working within the same field.

The Committee desires to express its appreciation of the hearty response to its requests for cooperation. To those of the contributors whose statements had to be revised in form or volume, and to any investigators who may have been overlooked by this

Committee in its requests (it is realized that some such omissions may quite naturally have occurred in this first review of the field) it offers its apologies. It is further appreciated that for certain organizations the projects may not in all cases have been finally approved. They are included in the form reached at the time of compilation. Furthermore, the programs of many organizations were affected by the war and the still in a more or less unsettled state. In future editions of the program any such omissions an any errors which may have crept into this issue may be corrected. To this end the Committee earnestly desires the fullest criticism of its initial work and solicits suggestions of every kind as to the continuation of the program and improvements which may be incorporated in it.

The publication and distribution of this program was made possible only through the kindness of the National Research Council, to which the Committee acknowledges its gratitude. The Committee desires to acknowledge its obligation to Mr. Earl H. Frothingham, of the U. S. Forest Service, who performed practically the entire task of compilation.

DOMINION OF CANADA

DOMINION FORESTRY BRANCH

R. H. CAMPBELL, Director of Forestry, Ottawa

PETAWAWA FOREST EXPERIMENT STATION, Petawawa, Ontario

1. **Forest survey.** To obtain detailed information in regard to the various species and forest types, soil, site-classes, age classes and their distribution, quantity and quality of timber and reproduction, etc. Area examined 100 square miles.
Work begun in August, 1917. Preliminary report submitted. Survey completed 1919.
Working plan to be prepared.
Assigned to Forest Survey Staff.

2. **Thinnings.** Effects on remaining stand, individual trees, soil, and ground cover, of thinnings of different degrees and methods.
Work begun in 1918. Studies on permanent sample plots in stands of jack pine and in white pine and red pine with intermingled white spruce, white birch, red maple, aspen, and other hardwoods now under

way. Plots accurately mapped showing exact position and size of trees thinned out and of remaining trees.

To be continued and extended to other types.

Assigned to Head Office Staff, Ottawa.

3. Reproduction studies.

Work begun in 1918. Reproduction on old and recent burns studied on sample plots. Permanent sample plots also laid out to study reproduction of coniferous species in stands of *Betula alba papyrifera*. Reproduction studies in hardwood stands.

To be continued and extended, and forest conversion experiments to be undertaken.

Assigned to Head Office Staff, Ottawa.

4. Yield tables.

Work begun in 1918. Sample plots laid out for the study of yield in pure white pine, pure jack pine, and pure red pine stands.

To be continued and extended to other types.

Assigned to Head Office Staff, Ottawa.

5. Stemform and taper of trees.

Work begun in 1918. A study of stemform of white pine and red pine, using Prof. Tor Jonson's absolute form quotient as an expression of form or taper to verify or otherwise the application of this form quotient as a true expression of form or taper. The evidence is not sufficient in quantity to finally establish the applicability of Jonson's theories on white and red pine, but so far as it has been gone into, it all points to the conclusion that the absolute form quotient is an excellent expression of form and that if the absolute form quotient is known the taper of the tree in all other parts can be determined. Preliminary report submitted. The 1919 researches show that Jonson's theories are applicable.

This study is to be continued, and it is hoped that it will lead to the preparation of universal volume and taper tables based on diameter, total height, and form class.

Assigned to Head Office Staff, Ottawa.

TREE PLANTING DIVISION, Indian Head, Saskatchewan

Nursery practice

6. Propagation of box elder as 1-year seedlings; caragana as 1-year seedlings; green ash as 2-year seedlings.

Methods of sowing and cultivation well established. Can hardly be called research work now.

7. Propagation of willow and poplars from cutting stock.

8. Propagation from seed and transplanting of Scotch pine, jack pine, and white spruce.

Methods well established.

Artificial reproduction on forest reserves

9. To determine varieties best suited to different conditions of soil and different localities.

10. Investigating by experiment on fairly large scale method of direct sowing of pine and spruce on sandy soils.

11. **Planting out of seedlings and transplants of pine and spruce to determine best methods of planting under different conditions of soil and soil cover and best ages of plants.**

Trials on the nursery station

12. **In connection with hardiness;** several varieties are under test at present.

13. **Rates of growth of varieties under cultivation,** on the ordinary upland prairie soils, under conditions similar to those obtaining in average farm shelter belts and plantations. Species under investigation: box-elder, green ash, American elm, white birch, cottonwood, Russian poplars, willows, Scotch pine, jack pine, lodgepole pine, white spruce, Colorado spruce, Norway spruce, tamarack, European larch, Siberian larch.

Examinations of farmers' plantations

14. **To study comparison of growths in different locations and districts.**

15. **Effect of original preparations of soil on subsequent development.**

16. **Effects of cultivation on later developments of plantations.**

17. **Effects of spacing.**

18. **Extent to which grass and weeds influence the growth.**

19. **Behavior of different varieties in different mixtures.**

20. **Comparison of hardiness of same varieties in different districts.**

FOREST PRODUCTS LABORATORIES OF CANADA, Montreal, Quebec

21. **Mechanical, physical, and structural properties of woods grown in the Dominion of Canada,** based on tests of small clear specimens.

(*a*) Three shipments of Douglas fir tested. Results of tests published as Canadian Forestry Branch Bulletin 60. (*b*) One shipment each of black spruce, white spruce, Sitka spruce, white pine, and red pine tested, also two other shipments of Sitka spruce. (*c*) Work in progress on three shipments of western hemlock, two of yellow birch, two of sugar maple, and one shipment each of red spruce and eastern hemlock.

Work to be continued on other eastern and western Canadian species.

Assigned to Division of Timber Tests (Montreal) and Vancouver Branch Laboratory, Vancouver, B. C.

22. **Strength functions and physical properties of Nova Scotia mine timbers.**

(*a*) Tests completed on full-sized pit timbers of five different species. Both green and air-dried timbers tested in compression and bending. Results not yet published in printed form. (*b*) A species not previously used for mine timbers in Nova Scotia has been shown by the tests to be suitable for this purpose and has been successfully substituted for standard species by at least one company.

Bulletin to be prepared formally presenting the results of this investigation.

Assigned to Division of Timber Tests.

23. **Utilization of waste sulphite liquor (bibliography).**

Literature of the world reviewed. Publication issued as Canadian Forestry Branch Bulletin 66, in May, 1919.

Appendix to be added every two or three years.
Assigned to Division of Pulp and Paper.

24. The beating of paper pulp.
Preliminary work on motor tests and control apparatus partially completed.
Investigations to be continued when facilities are available.
Assigned to Division of Pulp and Paper.

25. Chemistry of wood. (*a*) Study of methods of analysis; (*b*) analysis of wood; (*c*) study of resins.
Study of methods of determination of cellulose completed and published. Analyses of five native species partially completed. Study of resins in same five species partially completed.
Analyses of wood and of resins to be continued.
Assigned to Division of Pulp and Paper.

26. Australian woods for pulp—*Eucalyptus rubida.*
Chemical and physical analysis of wood completed and submitted as Progress Report No. 1.
Project to be completed when facilities are available.
Assigned to Division of Pulp and Paper.

27. Relative durability of Canadian commercial woods.
Series of fungus bed tests, undertaken to test suitability of this method, completed.
Work on methods to be continued.
Assigned to Division of Timber Physics.

28. Fiber measurements of Canadian woods.
Work completed on eight species of conifers. Results on one species published; those on other seven being prepared for publication.
Investigation to be extended to other species.
Assigned to Division of Timber Physics.

29. Preparation of reference collection of wood section slides of Canadian and other woods and study of anatomy of these woods.
Slides prepared for a number of species. Study of anatomical features proceeding. Photomicrographs at different magnifications prepared.
Preparation of slides and study of various features of anatomy to be continued.
Assigned to Division of Timber Physics.

30. Railway ties—Section 1. Experimental treatment of jack pine and hemlock ties.
(*a*) Study of creosote treatment of jack pine and hemlock ties completed. Results reported in Canadian Forestry Branch Bulletin 67, "Creosote Treatment of Jack Pine and Eastern Hemlock for Cross Ties." Patents on process developed in the course of this work pending. (*b*) Seasoning study and creosote treatment of jack pine and hemlock ties for service tests have been undertaken.
Work on No. 2 to be completed.
Assigned to Division of Wood Preservation.

31. Paving blocks. Experimental investigation of some important factors in the creosote treatment of red pine paving blocks.
Effects of different preservatives and treatments on swelling and bleeding of the blocks are being investigated.

Work on bleeding and swelling tests to be continued.
Assigned to Division of Wood Preservation.

32. **Fence posts—Section 1.** Experimental creosote treatment of Russian poplar posts for service tests.
Posts have been treated and installed and yearly inspections are being made.
Reports of yearly inspections to be compiled and conclusions drawn.
Assigned to Division of Wood Preservation.

33. **Field survey of railroad ties.**
Study of Canadian conditions and ties in track proceeding.
Study to be completed and results compiled—to serve as a basis for research.
Assigned to Division of Wood Preservation.

34. **Field survey of timber exposed to influences favorable to its decay.**
Study of the following is proceeding: (*a*) decay of timber in buildings and structures; (*b*) decay of pulpwood in storage piles; (*c*) deterioration of stored groundwood pulp. Several articles bearing on (*a*) have been published in trade or technical journals.
To be continued and further matter to be prepared for publication.
Assigned to Pathologist, Division of Timber Physics.

COMMISSION OF CONSERVATION, Ottawa, Canada

CLYDE LEAVITT, Chief Forester

35. **Forest regeneration survey.** To determine the nature and amount of regeneration on cut-over pulpwood lands; the rate of growth of the commercial species on such lands. General reconnaissance, strip surveys, growth studies.
Begun in 1917 in cooperation with the Laurentide Company, Grand'-Mère, Quebec. Cooperation with the Riordon Pulp and Paper Company, Montreal, 1918, and with the Abitibi Power and Paper Co., Montreal, 1919 (limits in Ontario); collaboration with the New Brunswick Forest Service, 1918 and 1919.
Continuance with the present cooperators and extension to others as opportunity offers. Application of the same kind of investigation to burned-over lands.
Assigned to Dr. C. D. Howe in charge (Commission of Conservation of Canada). Field work in Quebec, Ontario and New Brunswick.

36. **Forest sample plot studies.** To make a detailed record of changing conditions through a series of years on permanent sample plots; to ascertain the influence of insect and fungus diseases in determining the composition of the forest and their influence upon the decay of slash; to study the factors which influence the regeneration and the rate of growth of the commercial species.
Three one-acre plots established on limits of the Laurentide Company and one on the limits of the Riordon Pulp and Paper Company in 1918. In 1919 there were established thirteen one-acre permanent sample plots on limits of the Laurentide Company, in addition to 160 acres of experimental cuttings; six one-acre sample plots on Riordon Company limits (Quebec); and 250 acres of experimental cuttings on Bathurst Lumber Company limits (New Brunswick); these are in cooperation

with the respective companies and with the New Brunswick Forest Service, as to work in that Province.*

To be continued with present cooperators and extended to others as opportunity offers.

Dr. C. D. Howe, forestry, Dr. W. H. Rankin, fungi (Commission of Conservation of Canada). Dr. J. M. Swaine, insects (Dominion Entomological Branch, Department of Agriculture, Canada).

DEPARTMENT OF AGRICULTURE, Ottawa, Canada

Entomological Branch

Division of Forest Insects

J. M. SWAINE, Chief of Division

37. **Bark-beetle injuries in British Columbia.** Injuries to the yellow pine, with emphasis on control of present serious infestation.

Investigations of these beetles, their habits and effective control measures, have been carried on since 1913; results summarized in several publications, chiefly in Bulletins 7 and 14 of the Dominion Entomological Branch.

Further work to include organization and supervision of control measures. Modified logging operations to be employed where feasible. Special effort to be made to check spread of present serious infestation. Further investigations to be made of important bark-beetle outbreaks in other western conifers, with organization of control measures where feasible.

Assigned to J. M. Swaine and Ralph Hopping, in charge of forest insect investigations in British Columbia.

38. **Biology of Canadian bark-beetles.**

A detailed study of the life history and habits of bark-beetles has been in progress since 1912, leading to development of methods of control, where needed.

Continuing.

Assigned to J. M. Swaine and Ralph Hopping.

39. **Classification of North American bark-beetles.**

Under way since 1912. Part of the results published in articles in the "Canadian Entomologist" and in Bulletins 7 and 14 of the Dominion Entomological Branch. Studies of immature forms in progress. Extensive collections from Europe and northern Asia have been obtained.

It is planned to continue this study, extending its scope to cover the fauna of Europe and northern Asia.

Assigned to J. M. Swaine.

40. **The balsam injury of eastern Canada.**

Has been carefully studied for several years. Studies of the injury and the factors involved are in progress in parts of Quebec and New Brunswick. Results point to slash burning as a necessary practice in eastern Canada. Publication: Agricultural Gazette of Canada, Vol. 6, No. 3, March, 1919.

Further studies planned for next season.

Assigned to J. M. Swaine, S. A. Graham, M. B. Dunn, in cooperation with J. D. Tothill in New Brunswick.

* (See also under Dominion Department of Agriculture, Entomological Branch, Forest sample plot studies.)

41. **Forest sample plot studies.** To determine the part taken by insects in the development of a stand of balsam under various conditions.

Permanent sample plots were laid out in 1918 at two stations in the Laurentians, and others are being established this summer in young balsam stands in different watersheds in Quebec Province and in New Brunswick. Trees numbered and described. Publication: Agricultural Gazette of Canada, Vol. 5, No. 9, p. 860, 1919. (See also under Dominion Commission of Conservation, Forest sample plot studies.)

Trees to be examined each season for insect injuries. It is planned to make these sample plots an important branch of the work, covering eventually all Canadian timber trees under different local conditions. Each group of sample plots will be a forest insect field station, in operation part or all of each summer.

Assigned to M. B. Dunn and other officers, in cooperation with the Commission of Conservation and the lumber companies on whose lands the plots are located.

42. **Larvae of wood-boring beetles.**

Studies have been undertaken in cooperation with biologic studies of wood-boring species.

Continuing.

Assigned to R. N. Chrystal.

43. **Studies with the genus** *Chermes* (spruce gall aphides).

Investigation of biology and control of these important enemies of spruce shade trees was in progress during 1914 and 1915, and is being continued this season.

Continuing.

Assigned to R. N. Chrystal.

44. **Borers in shade trees.**

Detailed studies of the biology and control of such important shade tree enemies as the bronze birch borer, the locust borer, and the carpenter worms of the genus *Prionoxystus* have been in progress for two seasons.

Continuing.

Assigned to C. B. Hutchings.

45. **Relation of weather phenomena to activities of forest insects.**

Under way.

Continuing.

C. B. Hutchings in cooperation with officer in charge of Natural Control Investigations.

46. **Life histories of forest insects.**

A field laboratory is maintained during the summer near Fort Coulonge, P. Q., for the study of forest insect biology. Special attention is paid to the families *Cerambycidae* and *Buprestidae*.

Continuing.

All officers of the Division; Laboratory in charge of J. I. Beaulne.

47. **Shade tree insect investigations.**

Attention is paid to the more important insect injuries to shade trees as they develop.

Continuing.

Officers of the Division.

BRITISH COLUMBIA

Department of Lands, Forest Branch, Victoria

M. A. Grainger, Chief Forester, Victoria

48. Combating insect damage to western yellow pine.

The danger of the total destruction of the stands of western yellow pine in the interior of the Province by Dendroctonus beetles has attracted attention for some years. Lately it has resulted in an active campaign of remedial measures.

The campaign of cutting the infected timber and destroying the broods is to be continued.

Assigned to Major Andrews and the local forestry officials in cooperation with Mr. Hopping of the Department of Agriculture, Division of Forest Insects, in charge of control measures.

49. Reproduction studies.

In 1914 in cooperation with the Commission of Conservation a study was made by Dr. C. D. Howe, and a report entitled "The Reproduction of Commercial Species in the Southern Coastal Forest of British Columbia" was published.

It is planned to make studies on timber sale areas to determine whether or not reproduction is adequate and of the right species, and if not, why not; and the best way to correct the defect. Brush disposal methods in their relation to reproduction will be studied. Permanent sample plots are also to be established.

Assigned to F. McVickar.

50. Volume tables.

Work was started on the coast in 1913 and 1914, and tables made for fir, hemlock, and cedar. In the interior work was carried on from time to time as circumstances permitted.

Existing data are being checked over, with a view to securing measurements for species in the regions where not already sufficient.

Assigned to F. McVickar.

51. Range of British Columbia trees.

In 1913 and 1914 maps were made showing the range of each tree species in British Columbia.

These maps will be sent out to the Forest Districts for revision by the men in the field.

Assigned to Field Staff.

52. Grazing.

The Grazing Commissioner, after a good deal of study and discussion with the ranchers, has divided the country into grazing districts, and has drawn up a series of grazing regulations.

Studies to be continued. Regulated grazing and cooperation with the Forest Branch in grazing matters to be further developed.

Assigned to T. P. McKenzie, Grazing Commissioner, and Grazing Assistant Copley.

53. Timber testing.

Last year a small forest products laboratory was established at the University of British Columbia. It is the purpose of this laboratory to attend to local problems in timber physics and wood utilization.

The work just begun is to be continued and extended.

Assigned to Forest Products Laboratory, University of British Columbia, Vancouver.

54. Forest resources of British Columbia.

The Commission of Conservation has been in cooperation with the Forest Branch in an investigation of British Columbia's resources. The results have been published in "Forests of British Columbia," by H. N. Whitford, Ph.D., and Roland D. Craig, F.E., Commission of Conservation, Ottawa, Canada, 1918.

This subject will be kept constantly in mind, and from time to time more accurate details will come up so that it is hoped in future to have a more extensive and accurate knowledge of this subject.

Assigned to The Staff.

55. Study of the growth of timber and preparation of yield tables as a basis for sustained yield management of Crown timber lands.

A certain amount of growth studies have been made from time to time; but have not been intensive enough to serve as a basis for working plans.

Intensive growth studies to be made and yield tables prepared, on certain areas of land unsuited to agriculture but well suited for timber crops.

Assigned to Staff of Assistants under direction of Major Andrews.

COMMERCIAL ORGANIZATIONS, CANADA

Abitibi Power and Paper Company, Limited, Iroquois Falls, Ontario

H. G. Schanche, Jr., Chief Forester

56. Regeneration survey. Carried on upon virgin and cut-over areas on the Company's holdings to secure data on the reproduction, its composition, amount, rate of growth, effect of logging methods in vogue.

Field work commenced May 15, 1919. Season's field work completed on September 20, 1919. Computation and working up of field data in progress January, 1920. (See also under Dominion Commission of Conservation, Forest regeneration survey.)

Field work to be continued during summer of 1920 in vicinity of Lake Abitibi.

Past work carried on jointly by Commission of Conservation and Forestry Department of the A. P. & P. Co. Work under direction of C. D. Howe, Ph.D., Forestry Faculty, University of Toronto. Same cooperative methods to be employed in 1920.

57. Growth studies. Complete tree analyses of 500 trees each of white spruce, black spruce, and balsam, of all diameter classes occurring in vicinity of Lake Abitibi, to ascertain rates of growth of the three species in specified regions and secure foundational data for compilation of volume tables.

Field work commenced Nov. 18, 1919, and was suspended Dec. 20, 1919. Compilation of data secured in the field in progress January, 1920.

Field work to be continued in fall of 1920.

Assigned to Forestry Department of the A. P. & P. Co., in conjunction with Forester of Commission of Conservation Staff.

58. Nursery experiments. A large quantity of coniferous species exotic to northeastern Canada will be introduced in the nursery operations

to ascertain which species may thrive and develop under local conditions; comparisons will be drawn between progress in development under local conditions, and progress made within the natural range.

Experiments to commence with the beginning of nursery operations in the spring of 1920.

Experiments to be carried on until definite conclusions shall have been reached.

Assigned to Superintendent of Nursery, Forestry Department A. P. & P. Co.

Laurentide Company, Limited, Grand' Mère, Quebec

Ellwood Wilson, Manager Forestry Division

59. **Brush disposal.** Methods and cost to determine best way from standpoint of reproduction and fire risk.

Work begun in 1913. Toplopping done in that year and examination since to determine time of rotting of lopped and unlopped tops. In 1917 began burning brush. Costs kept and work continued until present.

Examination of areas lopped and burnt will be continued and each operation will have brush burned.

Assigned to Forester in charge and local force.

60. **Thinning.** Effect of different degrees of thinning on planted spruce and pine.

Work begun in 1913 and continued to date. Plantations made under poplar and birch and also under hardwood. Acre plots laid out and permanently marked.

Work to be continued and number of plots increased.

Assigned to Forester in charge and local force.

61. **Nursery practice and planting.** Experiments in new technique in planting, cultivating, and transplanting. Fall and spring seeding and planting. Amounts of water and shade. Comparisons between trees dominant and suppressed from seed in nurseries and in field planting. Sample plots laid out where such dominants and suppressed trees are planted side by side on different slopes and aspects. Experiments with different fertilizers and soils.

Nursery started in 1909. Now contains 42 acres.

Work will be continued as outlined.

Assigned to Forester in charge and local force.

62. **Fire protection.** Use of seaplanes for fire protection.

Two seaplanes with 400 H. P. Liberty engines began work June 28, 1919.

Planes will fly every day when there is no rain or fog, to locate, report, and if possible extinguish forest fires.

Assigned to Pilot in charge and personnel.

63. **Mapping.** Test of aerial photography for mapping forest areas. Mosaic maps to be made from photographs at different altitudes. Cost data to be compiled. Will map 3000 square miles, 1920. Make progress maps of river drives.

Two seaplanes working.

Assigned to Pilot in charge and personnel.

64. Lumbering studies. To get lumbering costs under different conditions and to try to improve methods and machinery.

Work commenced in 1908 and continued. Work since 1917 on clearing lands for planting, marketing firewood, ties, telephone poles, fence posts, and lumber.

Work will be continued.

Assigned to Forester in charge and local force.

65. Utilization. To make ground wood pulp from hardwoods; birch, maple, beech, ash, and poplar.

1918: 60 cords of hardwood peeled by hand and ground. Very successful. 1919: 70 cords barked in tumbling barrels and made into ground wood pulp and then into paper; no difficulties. Knife barking also tried. Not successful.

Work will be continued and experiments made in floating, holding over for a season in water barking and transportation.

Assigned to Forester in charge and mill.

NEWFOUNDLAND

Commercial Organizations, Canada

Anglo-Newfoundland Development Company, Limited, Grand Falls, Newfoundland

Logging Department, J. D. Gilmour, General Logging Supt.

66. Forest survey.

Started before the war, and has been recommenced. (For statement of Company's policy and local conditions see "Forestry Progress in Newfoundland; How Lord Northcliffe's Company Aims to Maintain Its Forests as a Permanent Crop," by J. D. Gilmour, in Canadian Forestry Journal, Vol. 15, No. 6, June, 1919.)

Will eventually give a complete topographic and forest survey of the entire limits, nearly 2,500,000 acres, which, in accordance with the Company's policy, will be handled for permanency.

Assigned to J. D. Gilmour.

67. Measurement.

Volume tables for computing strip surveys have been made locally. Growth tables, showing increment in volume, diameter breasthigh, and height, for different species and types have been made, although in some cases they require strengthening by further data. These so far are based on complete stem analyses.

Assigned to J. D. Gilmour.

68. Regeneration.

Regeneration studies to determine what new growth has followed clear cuttings, partial cuttings, and old burns have been made.

Assigned to J. D. Gilmour.

69. Management. To determine commercial feasibility in the pulp business of any logging system which will give a better second crop.

In 1918 five sample plots (acres) for logging to various diameter limits were laid off for annual observation.

Annual observation of plots established. Establishment of new plots proposed. Plots expected to yield valuable data in four or five years with reference to windfall among trees left behind, and in a longer period, with regard to increased rate of growth, if any, among the same trees.

Assigned to J. D. Gilmour.

70. Slash burning.

Last spring a small amount of slash burning was tried, both as a protection against fire and because light fires in the past—as indicated by reproduction tallies on over 100 sample plots—have been followed by a much more satisfactory crop than have areas left covered with slash.

To be tried on a more extensive scale.

Assigned to J. D. Gilmour.

UNITED STATES

FEDERAL AGENCIES

U. S. DEPARTMENT OF AGRICULTURE

FOREST SERVICE

WILLIAM B. GREELEY, Forester

Branch of Research, Earle H. Clapp, Assistant Forester, in charge.
S. T. Dana, Assistant Chief of Branch.
Office of Dendrology, George B. Sudworth, Dendrologist.
Office of Forest Investigations—Raphael Zon, Chief.
District 1 (Northern), Missoula, Mont.
Priest River Experiment Station, Priest River, Idaho.
J. A. Larsen, in charge.
District 2 (Rocky Mountain), Denver, Colo.
Fremont Experiment Station, Colorado Springs, Colo.
C. G. Bates, in charge.
Wagon Wheel Gap Experiment Station, Wagon Wheel Gap, Colo.
J. H. Jarboe, of the Weather Bureau, in charge.
District 3 (Southwestern), Albuquerque, N. Mex.
Fort Valley Experiment Station, Flagstaff, Ariz.
G. A. Pearson, in charge.
District 6 (North Pacific), Portland, Ore.
Wind River Experiment Station, Stabler, Wash.
J. V. Hofmann, in charge.
Districts 7 and 8 (Eastern), Washington, D. C.
Chief, Office of Forest Investigations, in charge.
(Other investigators are also assigned to the above Districts and to District 4 (Ogden, Utah) and 5 (San Francisco, Calif.) for general and special investigations.)
Forest Products Laboratory, Madison, Wis., C. P. Winslow, Director.
O. M. Butler, Assistant Director.
Derived Products—L. F. Hawley, in charge.
Pulp and Paper—Otto Kress, in charge.
Timber Mechanics—J. A. Newlin, in charge.
Timber Physics—Rolf Thelen, in charge.
Wood Preservation—George M. Hunt, in charge.
Pathology—Paul V. Siggers, in charge.
Office of Forest Products, Washington, D. C.; H. S. Betts, Engineer in Forest Products, in charge.
Branch of Grazing—Will C. Barnes, Assistant Forester, in charge.
Grazing Studies—Wm. R. Chapline, Inspector of Grazing, in charge.
District 3.
Jornada Range Reserve, Las Cruces, N. Mex.
E. W. Nelson, in charge.

Santa Rita Range Reserve, Tucson, Ariz.
R. R. Hill, in charge
District 4.
Great Basin Experiment Station, Ephraim, Utah.
A. W. Sampson, in charge.
(Other investigators also assigned to the above and the other Districts for general and special investigations in grazing.)

In classifying Forest Service investigative projects the following method of designation is used: The general and the special subjects are indicated by their initials, the former a capital letter. The number assigned to the project follows, or, in case an individual species is the subject of the study, its number in the Forest Service classification is usually given. In case the project relates to a still more specific point, this is indicated by a key letter in parenthesis; where this is done the key is included at the head of the list. In many cases the District to which the project is assigned is indicated by initial and number. Examples: Fs–101 (d) is Forestation, seed studies, western yellow pine, effect of source of seed upon the resulting stock. Mb–3, D–2, is Management, brush disposal, project No. 3, District 2.

FOREST INVESTIGATIONS

DENDROLOGY

71. Forest trees of the United States. To bring together in a comprehensive manner all the available information on the common names, geographical distribution, botanical characteristics, occurrence, and habits of forest trees by groups or genera.

Work begun in 1886. "Forest Trees of the Pacific Slope," "Cypresses and Junipers of the Rocky Mountain Region," "The Spruce and Fir Trees of the Rocky Mountain Region," "The Pine Trees of the Rocky Mountain Region," and "Miscellaneous Conifers of the Rocky Mountain Region" are completed and published. The manuscript of "The Walnuts, Willows, Poplars, Birches, Alders, and Oaks of the Rocky Mountain Region" is nearly completed.

Material is now partly completed for the following bulletins: "Part VII, Hackberry, Mulberry, Sycamore, Service-berry, Hawthorne, Plums, and Cherries, and Leguminous Trees of the Rocky Mountain Region." "Part VIII, Maples, Ashes, and Miscellaneous Smaller Groups, Completing Broadleaf Species of the Rocky Mountain Region."

George B. Sudworth, in charge.

72. Forest distribution studies (project B-1, D-8). To secure information concerning the botanical and commercial range of North American trees, including the preparation of range maps.

Work begun in 1913. Routine work consists in compilation of range notes, preparation of maps for publication showing geographical ranges of tree species, and identification of species from specimens sent in. During the war information was supplied on the distribution of species of war value, and special maps were prepared. Contributions to trade journals on the nomenclature, distribution, and economic value of many species were made, including the pines of Central and South America, the walnuts, and the woods called cedar. A chart showing the distribution of all coniferous trees growing west of the 99th meridian has been completed.

To be continued in accordance with previous plans, with emphasis upon educational aspects, as follows: (1) Popular identification of

trees. Publications along the lines of the "Key to Common Kinds of Trees" (appendix to Farmer's Bull. 468). (2) An index of common names of the important timber trees of the world. A series of papers on nomenclature and distribution, now under way, will furnish the basis for such an index. (3) Preparation of articles dealing with the geographical distribution of North American trees, for publication in suitable journals. The charting of geographical distribution already completed for conifers growing west of the 99th meridian will be extended to include all important native trees.

Assigned to W. H. Lamb and Miss G. E. Wharton.

73. **Shrubs of the United States—Ceanothus (project B-2, D-8).** To secure information concerning the distinguishing characteristics and geographical distribution of the genus Ceanothus.

Work begun in 1913. Data collected consist of photographs of important types of Ceanothi, original type descriptions, data on economic value, and extensive information on the geographical distribution of the species, including a set of file maps showing the native range of each species. Enough material is on hand to warrant publication of popular and economic papers on the important and well-known species and of more technical papers on the little-known species and varieties.

To be completed with the preparation of reports from the material now on hand. Identification of species of Ceanothus for the Office of Grazing Studies, and others, will be continued under Project B-1, and additional data will be collected along certain lines.

Assigned to W. H. Lamb.

74. **Forest resources of Mexico, Central and South America (project B-3, D-8).** To bring together the available information on the timber resources of Mexico, Central and South America, as well as on other exotic woods, for use in correspondence.

Work begun in 1913. Additional notes have been secured on the forest resources of Cuba, Jamaica, Venezuela, Chili, and Colombia, and check lists of the trees of Brazil, Argentina, and Ecquador partly completed. A map of the forested area of Cuba has been prepared and a classification of the timbered areas of Mexico into natural forest regions begun.

The collection and compilation of data will be continued. As rapidly as possible this information will be presented in the form of popular articles for publication in lumber or other journals.

Assigned to Miss G. E. Wharton.

FORESTATION

General

75. **Relation of soil acidity to forest planting (project F-1, D-4).** To determine the causes of success or failure in forest planting on acid and alkaline soils.

Begun in 1909–10 on the Wallowa Forest, from a grazing standpoint. Previous to 1915 a number of soils were tested for acidity and alkalinity. During 1915 samples from a number of local soils were collected for testing. Seeds of western yellow pine, lodgepole pine, and Douglas fir have been sown in eight soils of different degrees of acidity and with

correspondingly different physical properties. Great Basin Experiment Station.

Indefinite, pending revision of original plans.

Assigned to A. W. Sampson.

Seed Studies, General

76. **Seed storage experiments (project Fs-1, D-8).** Seeds of six conifers stored in 13 localities; in five different containers; and under three different temperature conditions.

Main part of experiment completed in 1914. A few additional tests of seeds stored for 10 years were conducted during the winter of 1918–19.

Experiment completed; final report under preparation.

Assigned to C. R. Tillotson.

77. **Physical characteristics and vitality of forest tree seeds (project Fs-2, D-8).**

A large number of tests of coniferous seeds completed.

To be continued: will be extended to include study of hardwood seed.

Assigned to C. R. Tillotson.

78. **To determine best methods of seed extraction** .... *a*

79. **Comparative germination in greenhouse and field** .... *b*

80. **Seed production** .... *c*

81. **Effect of source of seed upon the resulting stock** .... *d*

82. **Physiological characteristics of seed and methods of stimulating germination** .... *e*

83. **Methods of storing seed** .... *f*

Work in this subject was started in 1910, and is assigned to investigative and planting staffs in the District concerned. Twenty-nine studies are now under way in five Districts, as follows:

District 1.

Western yellow pine Fs-101 (*b*). Progress report, Priest River, 1918. Continuing at Savanac Nursery.

Western yellow pine Fs-101 (*d*). Progress report, 1918. Continuing at Savanac Nursery and Priest River.

Western white pine Fs-102 (*b*). Progress report, Priest River, 1918. Continuing at Savanac Nursery.

Western white pine Fs-102 (*d*). Priest River; no work done. Working plan to be made.

Western larch Fs-141 (*b*). Progress report, Priest River, 1918. Continuing at Savanac and Priest River.

Douglas fir Fs-161 (*b*). Progress report, Priest River, 1918. Continuing at Savanac and Priest River.

Western red cedar Fs-182 (*b*). Continuing at Savanac and Priest River.

District 2.

Western yellow pine Fs-101 (*a, b, c, d*). (*a*) and (*b*) final reports under preparation; (*c*) continuing at Cochetopa, Colorado, and Harney National Forests; (*d*) continuing at Nebraska National Forest.

Lodgepole pine Fs-103 (*a, c, d*). (*a*) final reports under preparation; (*c*) continued at Gunnison and Medicine Bow National Forests; continued at Fremont National Forest.

Engelmann spruce Fs-146 (*b, c, d*). (*b*) final reports under preparation; (*c*) continuing at Uncompahgre and White River National Forests; (*d*) continuing at Fremont National Forest.

Seed Studies, Species

Douglas fir Fs-161 (*b, c, d*). (*b*) final reports under preparation; (*c*) continuing at Washakie and Pike National Forests; (*d*) continuing at Fremont National Forest.

District 3.

Western yellow pine Fs-101 (*d*). Fort Valley Experiment Station. Experiments carried on since 1908. A large number of plants have been field planted.. Conclusive data on effect of geographical source of seed secured, but data on effect of age and character of tree not conclusive. Publication: "The Influence of Age and Condition of the Tree upon Seed Production in Western Yellow Pine," by G. A. Pearson. Forest Service Circular 196, 1912.

Continuing. Several lots of stock to be field planted in 1919. All old plantations to be thoroughly examined; report now in preparation, to be completed in 1919.

District 5.

Western yellow pine Fs-101 (*d*).
Sugar pine Fs-104 (*d*).
Jeffrey pine Fs-108 (*d*).
Douglas fir Fs-161 (*d*).
Incense cedar Fs-181 (*d*). Installed in 1917–18, Feather River. Reports on behavior of seed and initial survival to be made next winter. Plots to be observed for an indefinite period for differences in growth.

District 6.

Douglas fir Fs-161 (*d*). Wind River Nursery; progress report 1918. Publications: "Incidental Results of a Study of Douglas Fir Seed in the Pacific Northwest," by C. P. Willis, Jour. Forestry, Dec. 1917, Vol. 15, No. 8, 991–1002; "A Study of Douglas Fir Seed," by C. P. Willis and J. V. Hofmann, Proc. Soc. Am. Foresters, April, 1915, Vol. 10, No. 3, 141–64; "Choosing the Best Tree Seeds: The Influence of Parental Character and Environment upon the Progeny of Douglas Fir," by C. J. Kraebel, Jour. of Heredity, Nov. 1917, Vol. 8, No. 11, 483–92.

Noble fir Fs-166 (*f*). Begun in winter of 1917–18, when seed stored under six different conditions. In the spring germination tests were made and counts throughout the summer. Wind River Experiment Station. Continuing. The tests will remain in storage for five years.

Amabilis fir Fs-169 (*f*).

Nursery practice	*Project*
84. Best amount of seed to sow	*a*
85. Time of sowing	*b*
86. Preliminary treatment of seed	*c*

87. **Depth of covering seed** .... *d*
88. **Methods of sowing** .... *e*
89. **Fertilizing** .... *f*
90. **Shading** .... *g*
91. **Watering** .... *h*
92. **Root development** .... *i*
93. **Time and method of transplanting** .... *j*
94. **Methods of retarding spring growth in nursery stock** .... *k*
95. **Best method of packing stock for shipment** .... *l*
96. **Value of various mulches in seed and transplant beds** .... *m*
97. **Protection of nursery stock from frost and winter injury** ..... *n*

Work in this subject was started in 1910, and is variously assigned in different Districts to members of the planting and investigative staffs: 57 studies are now under way:

District 1.

Western yellow pine Fn-101 (*a, b, c, f, g, i*). Continuing at Savanac; (*a*) and (*b*) to be completed 1920.

Western white pine Fn-102 (*b, c, d, g, i*). (*b*) Completed at Priest River. Continuing at Savanac; (*g*) to be completed in 1920.

Engelmann spruce Fn-146 (*a, b*). Continuing at Savanac.

Western red cedar Fn-182 (*b, d*). Continuing at Savanac.

District 2.

Western yellow pine Fn-101 (*g, i*). Nebraska National Forest. Probably conclusive results 1919.

Norway pine Fn-105 (*b, j*). Minnesota National Forest. Final report about 1923.

Jack pine Fn-106 (*g, i*). Nebraska National Forest. Final report in 1919, probably.

Eastern white pine Fn-107 (*b, j*). Minnesota National Forest. Final report about 1923.

District 3.

Western yellow pine Fn-101 (*a*). Work at Ft. Bayard Nursery completed. Final report Ft. Valley Experiment Station and Gallinas Nursery under preparation.

Western yellow pine Fn-101 (*j*). Work at Ft. Bayard Nursery completed. Final report Ft. Valley Experiment Station and Gallinas Nursery under preparation.

Engelmann spruce Fn-146 (*a, j*). Gallinas Nursery. Continuing.

Douglas fir Fn-161 (*a, j*). Gallinas Nursery. Continuing.

District 4.

Lodgepole pine Fn-103 (*g*). Great Basin Experiment Station. Continuing.

Engelmann spruce Fn-146 (*g*). Great Basin Experiment Station begun in 1918. Continuing.

Douglas fir Fn-161 (*a, c, d, g, n*), (*a, d, g, n*). Cottonwood Nursery begun in 1918. Continuing, except (*c*), final report in preparation.

District 5.

Western yellow pine	Fn-101 (*b, g, h*)	Converse Nursery; field work completed; final reports under preparation.
Sugar pine	Fn-104 (*c*)	
Jeffrey pine	Fn-108 (*b, g, h*)	
Incense cedar	Fn-181 (*b, g, h*)	

Red fir Fn-168 (*d*). Discontinued; final report under preparation.

Austrian pine Fn-501 (*b*). Completed; final report under preparation.

Deodar cedar Fn-504 (*g*). Completed; final report under preparation.

District 6.

Western white pine	Fn-102 (*c*)	Wind River Experiment Station. (*a*) Different densities of fall and spring-sown 2–0 stock; survival counts taken
Douglas fir	Fn-161 (*c, f*)	
Noble fir	Fn-166 (*a, b, c*)	
Amabilis fir	Fn-169 (*a, b*)	

of bud condition and size of tops and roots when transplanted and again in the fall. Stock to be field planted in spring and examined in fall for survival, growth, and bud maturity. (*b*) Records of germination, daily soil temperature, bud maturity, size of tops and roots, damping off, and cultures of diseases causing loss. (*c*) Second annual examination of plantations; data on current and total growth and bud maturity. Annual examination in fall to determine growth and bud maturity. (*f*) Nine different fertilizers; data on germination, bud maturity, size of tops and roots, losses through damping-off, and cultures of diseases causing loss. Continued observations during second year in seed beds. Record to be made in the fall of bud maturity, size of roots and tops, and density of stand.

Sowing and planting, general

98. Value of native plants as indicators of planting sites (project Fp-6, D-4). To ascertain the value of native vegetation as indicative of soil and climatic conditions under which certain important conifers may be successfully planted.

Begun in 1916. Work carried on at the Great Basin Experiment Station. Studies made of the root system and successions in the oak brush zone, and a preliminary study of the western yellow pine type on the Manti National Forest, in which a meteorological station was established. Later supplemented by soil analyses. See Korstian, C. F., "The Indicator Significance of Native Vegetation in the Determination of Forest Sites." Plant World, Vol. 20, No. 9, pp. 267–287, September, 1917.

Advisability of further work along the lines suggested by the District is doubtful.

Assigned to C. F. Korstian.

99. Preparation of two farmers' bulletins on planting (project Fp-18, D-8).

Bulletin entitled "The Growing of Hardwood Trees in the Home Nursery and Planting them on the Farm" completed for publication.

Bulletin on the planting of coniferous trees in course of preparation. Additional species to be transplanted from the nursery. Further planting to be done as new material becomes available.

Assigned to C. R. Tillotson.

100. Arboretum, establishment and maintenance (project **Fp-2, D-6,** 8). D-8 project formerly designated as Z-3, D-8, Special Studies.

District 7.

At Wind River Experiment Station. In 1918 trees relabeled and numbered, and data on growth and condition recorded. Assigned to investigative staff.

District 8.

At Rock Creek Park, Washington, D. C. Begun 1912. About 669 conifers and 960 hardwoods, of about 225 species and varieties, now growing. Practically all the broadleafed trees except ginkgo were more or less seriously injured by the 17-year locust in June, 1919, and a number will probably die as a result.

Sowing and planting, species.

101. **The most suitable species** .... *a*
102. **Classes of stock to use** .... *b*
103. **Advantages of grading seedlings** .... (b^2, D-2)
104. **Best season for sowing and planting** .... *c*
105. **Best methods of sowing and planting** .... *d*
106. **Effect of cover** .... *e*
107. **Sites most suitable to the different species** .... *f*

Work in this subject was started in 1910, and is assigned to the planting and investigative staff except where noted; 104 studies are now under way:

District 1.

Western yellow pine	Fp-101 (*b, c, d, f*)	At Savanac Nursery; (*b*) also at Priest River Experiment Station.
Western white pine	Fp-102 (*b*)	Priest River and Wallace, Idaho; progress report 1919.
Western white pine	Fp-102 (*c*)	Work at Priest River completed 1918.
Western white pine	Fp-102 (*d*)	Haugan, Mont., and Wallace, Idaho; completed at Priest River 1918.
Western white pine	Fp-102 (*f*)	Haugan, Mont., and Wallace, Idaho; progress report 1917.
Western larch	Fp-141 (*b, c, d, f*)	Haugan, Mont., and Wallace, Idaho; completed at Priest River, 1917.
Engelmann spruce	Fp-146 (*d*)	
Sugar pine	Fp-104 (*a*)	Individual progress reports, submitted in 1918, will be combined into a general report. Some tests are being made at Wallace under the supervision of the Office of Planting. Most of the tests are at Priest River, and a number at the Savanac Nursery. A new comprehensive working plan to be prepared and new installations made on more suitable sites. Conclusive data not forthcoming until 1930.
Norway pine	Fp-105 (*a*)	
Eastern white pine	Fp-107 (*a*)	
Colo. blue spruce	Fp-149 (*a*)	
Bigtree	Fp-177 (*a*)	
Hardwoods	Fp-300 (*a*)	
Scotch pine	Fp-500 (*a*)	
Austrian pine	Fp-501 (*a*)	
Norway spruce	Fp-505 (*a*)	
European larch	Fp-506 (*a*)	
Japanese larch	Fp-507 (*a*)	
Siberian larch	Fp-508 (*a*)	

District 2.

Western yellow pine	Fp-101 (*a*, *b*[1], *b*[2], *c*)	(*a*, *b*[1], *b*[2]) Nebraska, (*c*) Fremont National Forests; final reports under preparation.
Western yellow pine	Fp-101 (*f*)	Nebraska National Forest.
Western white pine	Fp-102 (*a*)	Fremont National Forest; final report expected in 1919.
Lodgepole pine	Fp-103 (*a*, *c*)	(*a*) Fremont, (*c*) Colorado and Routt National Forests; (*a*) continuing, (*c*) final report under preparation.
Norway pine	Fp-105 (*a*, *b*)	(*a*) Fremont, medicine Bow and Nebraska National Forests; (*b*) Michigan National Forest; (*a*) final report due 1919; (*b*) continuing.
Jack pine	Fp-106 (*b*[2])	Nebraska National Forest; final report under preparation.
Engelmann spruce	Fp-146 (*c*)	Fremont and Cochetopa National Forests; final report under preparation.
Douglas fir	Fp-161 (*a*, *c*)	(*a*) Arapaho and Medicine Bow; (*c*) Fremont, Bighorn, Durango and Sopris National Forests; (*a*) continuing; (*c*) final report under preparation.
Scotch pine	Fp-500 (*a*, *b*)	(*a*) Fremont, Nebraska, (*b*) Nebraska National Forests; (*a*) continuing; (*b*) final report under preparation.
Austrian pine	Fp-501 (*a*)	Fremont, Nebraska and Uncompahgre National Forests; final report expected in 1919.
Corsican pine	Fp-502 (*a*)	Nebraska National Forest; final report expected in 1919.
Norway spruce	Fp-505 (*a*)	Fremont National Forest; final report expected in 1919.
Japanese larch	Fp-507 (*a*)	Fremont National Forest; continuing
Siberian larch	Fp-508 (*a*)	Fremont National Forest; to be completed in 1920.

District 3.

Western yellow pine	Fp-101 (*f*)	Ft. Valley Experiment Station, Ft. Bayard and Gallinas Nurseries Continuing.
Engelmann spruce	Fp-146 (*c*, *f*)	(*c*) Gallinas Nursery, (*f*) Ft. Valley Expt. Station, and Gallinas Nursery; continuing.
Douglas fir	Fp-161 (*c*, *f*)	Gallinas Nursery; continuing.
Norway spruce	Fp-505 (*a*)	Fort Valley Experiment Station; continuing.

District 4.

Western yellow pine	Fp-101 (*b*)	Great Basin Experiment Station, Cottonwood Nurseries.
Western yellow pine	Fp-101 (*c*)	Great Basin Experiment Station.

Western yellow pine	Fp-101 (*f*)	Great Basin Experiment Station; Fishlake and Targhee National Forests, Cottonwood Nursery.
Western white pine	Fp-102 (*a*)	Continuing.
Lodgepole pine	Fp-103 (*b, f*)	(*b*) Targhee National Forest; (*f*) Great Basin Experiment Station and Targhee National Forest.
Engelmann spruce	Fp-146 (*b, f*)	(*b*) Great Basin Experiment Station; (*f*) Great Basin Experiment Station and Cottonwood Nursery.
Blue spruce	Fp-149 (*f*)	Great Basin Experiment Station.
Douglas fir	Fp-161 (*b*)	Great Basin Experiment Station; and Targhee National Forest.
Douglas fir	Fp-161 (*f*)	Great Basin Experiment Station; Targhee Cache and Wasatch National Forests.
Norway spruce	Fp-505 (*f*)	Great Basin Experiment Station.

District 5.

Western yellow pine	Fp-101 (*a, b, c, f*)	Converse Nursery.
Western yellow pine	Fp-101 (*c, f*)	Feather River Experiment Station.
Sugar pine	Fp-104 (*c, f*)	Feather River Experiment Station.
Jeffrey pine	Fp-108 (*c, f*)	Feather River Experiment Station.
Jeffrey pine	Fp-108 (*a, b, c, e, f*)	Converse Nursery.
Douglas fir	Fp-161 (*c, f*)	Feather River Experiment Station.
White fir	Fp-167 (*c, f*)	Feather River Experiment Station.
Incense cedar	Fp-181 (*c, f*)	Feather River Experiment Station.
Incense cedar	Fp-181 (*c, f*)	Converse Nursery.

All planting experiments at Converse Nursery and the (*c*) experiments at Feather River to be completed by submission of a final report this winter. At Feather River the (*f*) experiments are in a broad sense continuous, though a report will be submitted this winter.

District 6.

Western yellow pine	Fp-101 (*c,d*)	Wind River Experiment Station.
Noble fir	Fp-166 (*c, d, f*)	Final reports on (*c*), (*d*), and (*f*) under preparation. (*a*), continuous.
Siberian larch	Fp-108 (*a*)	Assigned to investigative staff.

District 7.

Maritime pine	Fp-503 (*a*)	Florida National Forest.
Eucalyptus	Fp-700 (*a*)	Assigned to investigative staff D-8.
Cork oak	Fp-701 (*a*)	

District 8.

Loblolly pine Fp-111 (*a*). Begun in 1908, when 7 seed beds and 5 half-acre plots were started, the latter by direct seeding; few seeds germinated, and seedlings later killed by drought. From 1910 to 1913 8 plots aggregating about 8.4 acres were planted with seedlings or transplants under different conditions; about 3 acres showed success when examined in 1919. Results indicate success of seedlings (when once established) on the sands of south Jersey, but failure on heavier clay

soils of north Jersey due to injury to terminals from early or late cold winds.

Assigned to W. R. Mattoon, in cooperation with New Jersey State Forester.

Completed.

Maritime pine Fp-503 (*a*). Begun in 1912. From 1912 to 1914 12 plots aggregating about 5 acres were started, mostly by direct seeding. Results when examined in 1919 show almost total failure. Seedlings died off rapidly due apparently to winter killing. Surviving two per cent of seedlings planted (2–0) appear healthy. Maritime pine apparently not adapted to the sandy soils of south Jersey, being injured by winter-killing and perhaps by drought and hot sun. Assigned to W. R. Mattoon, in cooperation with New Jersey State Forester. Completed.

Loblolly pine Fp-111 (*a*, *c*)
Longleaf pine Fp-112 (*a*) } Summerville, S. C.
Shortleaf pine Fp-113 (*a*)

Plot burned over February, 1917. Previous plantation destroyed. Seed-spot and broadcast sowing planned for March, 1918, not carried out on account of the war. Definite plans for continuing this project have not been made. Assigned to W. R. Mattoon, in cooperation with Clemson College Expt. Station.

Slash pine Fp-118 (*a*). Summerville, S. C.

Plots established 1918 (spring). No plans pending examination. Assigned to W. R. Mattoon, in cooperation with Clemson College Expt. Station.

Willows Fp-301. Development of American willows, Arlington, Va. Future plans indefinite.

Assigned to Office of Forest Investigations.

INFLUENCES.

108. Effect of forest and brush cover on streamflow. Douglas fir and spruce type (project I-1, D-2).

Begun in 1910 at the Wagon Wheel Gap Experiment Station. Records for eight full years completed October 31, 1918. Denudation of Watershed B in progress, summer of 1919.

After denudation is completed observations will be continued on the two watersheds for several more years. Meanwhile the weather and stream data are being analyzed by both the Weather Bureau and the Forest Service, and the material published in the Monthly Weather Review.

Assigned to C. G. Bates in cooperation with the Weather Bureau.

109. Effect of willow planting on erosion (project I-2, D-2). To test the possibility of checking erosion in eroding mountain gullies in the Pike's Peak region by planting willow cuttings.

Plantings of willow cuttings along a single gully were made in 1910, 1911, 1912, and 1916. Although the percentage of survival has each year been low, the loose soil spots in the gully are gradually being filled. The main record in the past few years has been a series of photographs taken annually to show the change which takes place. The photos taken in 1915 and 1916 were failures.

Continuing. The photographic record is to be kept up for a number of years, until conditions become stable.

Assigned to Fremont Experiment Station.

110. Influence on streamflow of (1) chaparral cover, (2) fires in the chaparral, and (3) check dams (project I-1, D-5).

Begun in 1916 on the Angeles Forest. Progress reports on "Effect of Chaparral on Streamflow, Waterman and Devil Canyons," and "Effect of Check Dams on Storm Waters," submitted in 1916. Descriptive reports on eight other canyons submitted in 1918–19. A method of rating the protective value of chaparral so as largely to eliminate the variable factor of individual judgment was devised. Mapping of the forest cover of the important watersheds completed.

A more intensive study of small selected watersheds similar to the Wagon Wheel Gap project is needed to place the conclusions on a firm basis. Its initiation will depend, however, upon available funds and future experimental work in California.

Assigned to E. N. Munns, in cooperation with Office of Engineering (Forest Service) and the Geological Survey.

111. Dissipating effect of chaparral and forest cover on precipitation (project I-2, D-5). To determine the relative value of chaparral and forest cover as a conserver of water as indicated by the quantity of precipitation reaching the ground on adjoining areas of forest and chaparral, the rate of evaporation, etc.

Work begun in 1913 and continued until the abandonment of the Converse Experiment Station on June 30, 1917. Daily records taken of temperature, precipitation, humidity, and soil moisture, and data worked up in monthly decades.

Final report under preparation.

Assigned to E. N. Munns.

112. Influence of forests upon melting of winter snow (project I-1, D-6).

Begun 1916, Columbia and Deschutes Forests, on representative drainage basins. Semi-weekly observations and measurements of the melting of snow made at several sites in each locality representative of various exposures in forested and non-forested spots. Publication: "Influence of Forests Upon the Melting of Snow in the Cascade Range," by A. A. Griffin, U. S. Weather Bureau, Monthly Weather Review, July, 1918, Vol. 46, No. 7, 324–7.

Completed.

Assigned to A. A. Griffin and W. J. Sproat.

MANAGEMENT

General

113. Study of plantations on the Biltmore Estate, with special reference to their past history, present condition, and future management (project M-1, D-7). To determine the results that may be secured from artificial reforestation with various species in the Southern Appalachians.

Begun in 1915. During 1916 thinnings were made on four plantations on the Biltmore Estate and sample plots were established. These plots to be remeasured every five years.

If possible, additional thinnings will be made on other plantations on the Biltmore Estate and sample plots established.

Assigned to V. Rhoades and Office of Forest Investigations, D-8.

114. Woodlot management studies (project M-5, D-8). To bring together all available information on the management of woodlots in the

United States as a basis for improved methods of marketing woodlot products and better care of the woodlot. (See also under Forest Economics, Project E-10, D-8.)

Work begun in 1913, in cooperation with various States. Cooperative reports published for the States of Maine, Wisconsin, Michigan, Indiana, Kentucky, Tennessee, Missouri, South Carolina, and Georgia. Publications pending for the States of North Carolina and West Virginia. Three general woodlot bulletins have been published by the U. S. Department of Agriculture.

No additional work contemplated for the ensuing year.

Assigned to Office of Forest Investigations.

Brush disposal

115. Methods of brush disposal (projects Mb-1, D-1, 3, 4). To determine the most effective and cheapest method of brush disposal, taking into consideration reproduction, fire risk, and effect of grazing.

District 1.

(*a*) Lodgepole pine. Deerlodge Forest. Work on new project yet to be started. Publication: "Brush Disposal in Lodgepole Pine Cuttings," by D. T. Mason, Proc. Soc. Amer. Foresters, Oct. 1915, Vol. 10, No. 4, 399–404.

Continuing.

Assigned to investigative staff.

District 3.

(*b*) Western yellow pine. Coconino Forest. Begun in 1908, when brush was scattered on an area of 126 acres under fence. Examinations made every 1 or 2 years show both beneficial and detrimental effects. Practice has recently been greatly influenced by Dr. Long's results in studies of progress of decay (projects Mb-2 and Mb-3). Plans for this project (Mb-1) extended in 1916–17 to cover all phases of brush disposal and correlate all available data, particularly timber sale and fire reports, toward formulating a sound brush disposal policy. Work along new lines interrupted in 1917, after a 3 months' study by W. L. Scofield. Publications: "Brush Disposal—Fort Valley Experiment Station," by G. A. Pearson, Rev. Forest Service Investigations, 1913, Vol. 2, 78–81.

Continuing. To be extended from the Coconino and Tusayan to other Forests. The compilation of data from all available sources to be completed this year, if a man becomes available for the work.

Assigned to investigative staff.

District 4.

(*c*) Sheep grazing to reduce fire damage in lodgepole pine slash. Wasatch Forest. Begun in 1915, when 5 acres were fenced and the brush on one part piled and burned, on the other part scattered. Check area established outside of the fence in 1916.

Continuing.

Assigned to investigative staff.

116. Investigations on the rotting of slash in relation to the different methods of brush disposal (projects Mb-2, D-1; Mb-2, D-3, formerly designated Pd-6, D-3; Mb-3, D-3, formerly designated Pd-7, D-3, To determine the factors governing the rotting of brush and logs.

District 1.

(*a*) New project (Project Mb-2, D-1).

Extensive study planned for this year. Date of completion indefinite.

Assigned to Dr. J. R. Weir, Forest Pathologist.

District 3.

(*b*) Rate of decay of logs on burns on municipal watersheds in relation to the run-off (Project Mb-2, D-3). Begun as a project in 1916, although some work had been done before. Preliminary study indicates that 30–40 years' decay of logs will terminate retarding influence on run-off. *Lenzites sapiaria* practically the only fungus found causing the rotting of lots on these burns.

Continuing for at least one more year.

Assigned to Dr. W. H. Long, Forest Pathologist.

(*c*) Rate of decay, causes of difference in rate, effect upon reproduction, and other features, when slash is (1) piled, (2) scattered, and (3) pulled. (Project Mb-3, D-3). Begun as a project in 1916, although some work had been done before. In brush piled in the western yellow pine type progress of decay is from top of pile downwards, as sun's rays are admitted; decay usually more rapid when unlopped than when lopped and scattered. In Arkansas decay in piles is from both top and bottom. Two groups of fungi thus demonstrated: (1) ground fungi, requiring moisture; (2) fungi which apparently need little moisture including most fungi in District 3 which rot slash.

Continuing for at least one more year.

Assigned to Dr. W. H. Long, Forest Pathologist.

Methods of cutting

117. **Effects of different methods of cutting.** To determine the best methods of cutting in different forest types to secure natural reproduction in the shortest possible time. There are now 14 experiments under way in seven Districts

District 1.

(*a*) Western white pine, western larch, western yellow pine, Douglas fir, and lodgepole pine on the Kaniksu, Coeur d'Alene, Pend Oreille, Clearwater, and Deerlodge (Mc-1, D-1). Studies begun on 30 areas in the western white pine type in 1912–13, yielding evidence in support of the theory that white pine seed is capable of lying over in the duff for several years and of then germinating upon introduction of greater heat and light admitted after cutting operations. This evidence led to a radical change in marking rules and methods of brush disposal in white pine type. In 1914 a one-acre plot was established on the Coeur d'Alene Forest, and about 20 pounds of fresh white pine seed was placed in several series of wire baskets at different depths in the duff and under different degrees of shading, one basket under each depth and degree of shading to be taken up each year for 15 years and germinated, another to be subjected to a burning test. In 1915 intensive studies were made of the revised marking rules and two permanent plots of 4 acres each were laid out. Further revision of marking rules was prepared as a result of these studies. In 1916 special studies of girdling were conducted, sample plots reexamined, and a progress report prepared. Additional plots were laid out and existing plots reexamined in 1917–18. Emphasis was placed on methods of cutting in white pine and on de-

termination of the extent and conditions under which reproduction can be depended upon from seed stored in the duff.

To be continued in accordance with the working plan.

Assigned to investigative staff.

District 2.

(*b*) Lodgepole pine, Medicine Bow Project (Mc-1, D-2). Begun in 1909, when eight plots representing selection, group selection, and clear-cutting methods were established. First complete reproduction count in 1913 showed greatest number of seedlings in group selection, next best under selection, next under unbroken canopy, and fewest, but much the most thrifty, in clear cutting (about 4,000 per acre). Under all methods burning brush proves more favorable to germination than scattering. Second count, in 1915, substantiated these conclusions. Progress report on "Lodgepole Cutting System with a View to Reproduction," by Frank B. Notestein, submitted November 5, 1915.

Semi-final report expected in 1921.

Assigned to C. G. Bates and local forest force.

(*c*) Lodgepole pine, Gunnison (Mc-2, D-2). Begun in 1911 on 60 acres cut experimentally in seven strips representing (1) very heavy and (2) moderate thinning; (3) clear cut 200 and (4) 300 feet wide; (5) uncut 150, (6) 200, and (7) 400 feet wide. In 1913 two continuous strips of 10′ x 10′ sample plots transecting the major strips were laid out and counts made, which show practically no reproduction on the uncut strips, but from 600 to 5400 seedlings per acre on the cut-over strips, the number being in all but one case directly proportionate to present light intensity. Second count, in 1916, shows that good trees are becoming established only in clear-cut areas and those thinned most heavily. Progress reports by H. S. Borden, 1913 and 1916.

Continuing. Third reproduction count to be made in 1919.

Assigned to C. G. Bates and local forest force.

(*d*) Engelmann spruce—Fremont, Holy Cross, Rio Grande (Project Mc-3, D-2). Working plans were prepared in 1911 and 1913. Plots were laid out on the Rio Grande in 1913–14, and on the Holy Cross in 1914. Lack of timber sale opportunities has prevented more than preliminary work up to the present.

Continuing.

Assigned to C. G. Bates and local forest force.

(*e*) Douglas fir—Fremont, Pike (Project Mc-4, D-2). Attempts at beginning this project were made in 1910, 1911 and 1912, but nothing accomplished until 1913 when work was begun under a new working plan; four 1-acre plots, cut by selection, shelterwood, and clear-cutting systems, with one intact control plot, were established; brush largely burned, and all existing reproduction less than $4^1/_2$ feet high destroyed. Partial count of reproduction made in 1915. Complete reproduction count made in 1916 showed a surprisingly large amount of new germination from the 1914 seed crop, the most seedlings being in the uncut check plot where the density is very great. The reproduction in the clear-cut area is largely of other species than Douglas fir, indicating that seeding is by animal agencies rather than by wind. A progress report was prepared in 1917.

Continuing. Reproduction counts to cover 20 per cent of the area of each plot to be made in the fall of each year. Growth measurements

on the stands left after cutting will be made at intervals of about five years.

Assigned to C. G. Bates and local forest force.

(*f*) Spruce, Balsam—Leadville (Project Mc-5, D-2). Begun in 1911 and original survey completed 1912. Covers four 1-acre plots cut about 15, 30, 40, and 43 per cent respectively. All plots showed at outset nearly 50 per cent balsam in seedling and 30 per cent in sapling class. Reexamined in 1914 and 1915–16. No conclusive results as yet.

Progress report for 1919 under preparation.

Assigned to C. G. Bates and local forest force.

District 3.

(*g*) Western yellow pine and Douglas fir—Fort Valley (Project Mc-2, D-3). Begun in 1909. Nineteen permanent sample plots aggregating about 2000 acres have been established on the Coconino, Datil, Apache, Pecos, Jemez, and Gila Forests. About 90 per cent of the acreage is in the form of "extensive" and 10 per cent of "intensive" plots. Most of these plots have been remeasured once. Results up to 1918 are embodied in "Studies of Yield and Reproduction of Western Yellow Pine in Arizona and New Mexico," by G. A. Pearson, Jour. Forestry, Vol. 16, No. 3, March, 1918, pp. 273–293.

Continuing. The schedule is arranged so that several plots are due for remeasurement each year. In 1919 some 1200 acres, established 10 years, to be remeasured.

Assigned to G. A. Pearson and investigative staff.

District 4.

(*h*) Aspen—Great Basin (Project Mc-1, D-4). Begun in 1912–13, when two permanent plots established, to determine (1) relative vigor of sprouting on areas clear cut in autumn, spring, and midsummer, and (2) effect of cutting out the prop sizes (7″ — 10″ DBH) from all aged stands. In 1914 six additional plots were established, three for prop cuttings and three for clear cutting at different ages. In 1915 small plots were laid out to study the effect of thinning sprouts, and transects were established on three plots cut in 1914. In 1916 cuttings were made (1) in the spring, summer, and fall to determine best season for production of sprouts, and (2) in stands of different ages to determine age of maximum sprouting. Records on transects secured annually.

Plots to be remeasured in 1919 and the results combined with those of projects Mt-1, ME-2, and ME-3 as the basis for a report which will be submitted for publication.

Assigned to F. S. Baker.

(*i*) Western yellow pine—Payette (Project Mc-2, D-4). Begun in 1913, when three 5-acre plots were laid out, mapped, marked by the seed-tree method, and cut over. In each plot two reproduction plots of 500 sq. ft. each were established. In 1914–15, twelve 5-acre plots were laid out but not cut over. These comprise three plots, each to be cut by group selection, strip, and clear cutting with groups of seed trees; 13 reproduction plots were established, and a large number of light readings and soil moisture determinations made. A progress report was submitted by E. R. Hodson, in 1913.

Continuing.

Assigned to C. F. Korstian.

District 5.

(*j*) Study of cut-over areas on timber sale operations (Project Mc-1, D-5). Begun in 1910. Eight plots of 6.4 acres each were laid out on the Plumas Forest and all but two marked for cutting. Four plots cut over in 1913. Reproduction plots 50′ × 100′ were established and counts made previous to cutting on major plots. Permanent plots have been established on seven Forests. Progress reports were submitted in 1918 by S. B. Show, on plots on the Tahoe, Sierra, Plumas, and Sequoia Forests.

Continuing.

Assigned to S. B. Show.

(*k*) Practical aspects of the forest sanitation clause (Project Mc-2, D-5). Begun in 1911, but first extensive work done in 1913 on timber sales. Object (1) to secure a check of estimated cull of standing timber by actual sale; (2) to ascertain cost of handling diseased trees and snags under the Sanitation Clause and its bearing on the stumpage rate (3) to determine the actual saving in merchantable logs from trees cut under the Sanitation Clause. Method: On a representative area all trees, including snags, above diameter limit, are tagged and described by number. In lumbering, each log is identified with its tree, and the scale and deduction with reason for deduction, tallied. After completion of logging the area is surveyed and mapped.

Work to be continued on other sale areas as occasion arises.

Assigned to Dr. E. P. Meinecke, in cooperation with the investigative staff and local Forest officers.

District 6.

(*l*) Western yellow pine (Project Mc-101, D-6). Work begun in 1911 with establishment of a 40-acre plot on the Crater Forest, which was clear-cut and eliminated from the Forest as agricultural land in 1913. Two large plots were laid off on the Whitman in 1913 and marked for cutting; the cutting was done in 1914, the brush being burned, trees tagged and quadrats established. A field study of old yellow pine cut-over areas was made in 1914–15 by Field Assistant Weitknecht on and near the Whitman Forest, and continued in 1916 on the Minam, Ochoco, and Malheur Forests; a complete report on this work was submitted by Mr. Weitknecht in 1916 ("Study of Methods of Cutting Yellow Pine in Oregon." Revised and enlarged in 1917, under title "Yellow Pine Management Study in Oregon in 1916." Also "Preliminary Report of Yellow Pine Management Study of the Crater National Forest," 1917, and "Further Data on Distribution of Accelerated Increment in Western Yellow Pine," 1918. All manuscript reports by Mr. Weitknecht).

Continuing. Reports to be revised for publication.

Assigned to R. H. Weitknecht.

(*m*) Douglas fir (Project Mc-161, D-6). Begun in 1910 with establishment of a 75-acre plot on the Columbia Forest. Seed trees tagged, measured, and described, and the reproduction on 110 square rod sample plots counted. Remeasured in 1915, and results embodied in "Five Years' Growth of Douglas Fir Sample Plots," by T. T. Munger, Proc. Soc. Amer. Foresters, Vol. 10, No. 4, Oct., 1915, pp. 423–5.

Assigned to T. T. Munger.

Completed. Final report on six remeasurements now under preparation.

District 7.

(*n*) Study of cut-over areas, White Mountain National Forest (Project Mc-1, D-7). Working plan prepared in 1916. No definite results as yet.
Continuing.
Assigned to local Forest force.

Natural reproduction

118. Factors affecting natural reproduction. To determine means of encouraging reproduction and to find the rate of loss of seedlings during the early stages of development, and the factors responsible. Five experiments are now under way in five Districts:

District 1.

(*a*) Western white pine and associated species, Priest River Experiment Station and Coeur d'Alene Forest (Project Mr-1, D-1). Begun 1912. Final report, "A Study of the Factors Affecting Natural Reproduction," by J. A. Larsen, submitted 1918.
Assigned to J. A. Larsen.
Completed.
(*b*) Hastening regeneration of logged stands by sowing seed previous to cutting Priest River (Project Mr-2, D-1). New Project. Working plan prepared in 1919.
To be undertaken in connection with sales on the Experimental Forest and possibly the Kaniksu Forest. Can be completed in three years if suitable conditions are promptly available.
Assigned to J. A. Larsen.

District 2.

(*c*) Norway pine—Michigan National Forest (Project Mr-2, D-2). Begun in 1917 by Supervisor Hilton on plans prepared by Forest Examiner Bates. An area of about five acres was surrounded by a fire line and 98 plots, each 40 feet square, representing different conditions, laid out and mapped, showing location of all seed trees in and close to the plots. Fifteen selected sections mapped and described as to location and character of seed trees, Norway saplings and seedlings, and amounts of jack pine hardwoods and ground cover cones and soil samples secured for testing. Progress reports submitted in 1917 and 1918 by Mr. Hilton.
Continuing.
Assigned to C. G. Bates and H. C. Hilton.

District 3.

(*d*) Western yellow pine—Ft. Valley Experiment Station, Coconino and Apache National Forests (Project Mr-1, D-3). Begun on the Coconino in 1908, with establishment of five plots aggregating 12,475 sq. ft., and on the Apache in 1910 where two plots comprising 13,500 sq. ft. were laid out. Counts made on Coconino plots annually from 1908 to 1913, in 1915, and subsequently in connection with project Mc-2; on the Apache plots in 1910, 1911, 1914, and subsequently. Results up to 1918 are embodied in "Studies in Yield and Reproduction

of Western Yellow Pine in Arizona and New Mexico," by G. A. Pearson, Jour. Forestry, Vol. 16, No. 3, March, 1918, pp. 273–293. This study also formed the basis for Forest Service Circular 174, "Reproduction of Western Yellow Pine in the Southwest," by G. A. Pearson, 1910.

To be continued in connection with sample plot study, project Mc-2, and the study of forest types.

G. A. Pearson.

District 4.

(*e*) Douglas fir in central Idaho—Weiser and Payette Forests (Project Mr-1, D-4). Begun in 1910, when 10 plots, each 1 rod square, were laid out, the principal object being to study the effect of a good seed year on the reproduction of the succeeding year and the rate of drying out of the seedlings; plots counted twice in 1910 but not subsequently. In 1913, 23 plots 10 feet square were laid out on the Weiser and 34 on the Payette; and latter include 20 established by W. N. Sparhawk in connection with a grazing project, to determine extent to which Douglas fir is replacing yellow pine in the yellow pine type. The 34 Payette plots are mapped. Progress report by E. R. Hodson, 1913. In 1912–14, 131 other plots were established on the Payette in connection with the grazing project; these and the 30 seedling plots mapped in connection with the Mc-2 project afford data which may be used in this study.

Continuing. No work done since 1914.

Assigned to C. F. Korstian.

District 6.

(*f*) Douglas fir (Project Mr-1, D-6). Begun in 1913 with a detailed study of a 1902 burn on the Columbia Forest. A selected section was gridironed with east and west belt transects $8^1/_4$ feet wide and $2^1/_2$ chains apart, and the whole township then extensively studied by means of eight transects radiating from the section; area in transects; in the section, 372 acres; in the township, 1290 acres. This study established the principle that most of the reproduction that follows a simple burn is from seed stored in the forest floor before the fire and which retained its viability through the fire. Reproduction after compound burns studied in 1914 by transects in five areas on the Rainier Forest. Results embodied in comprehensive manuscript report on "The Management of Pacific Coast Douglas Fir" (three parts, 1917 and 1918), by J. V. Hofmann and C. J. Kraebel, and in "Natural Reproduction from Seed Stored in the Forest Floor," by J. V. Hofmann, Jour. of Agr. Research, Oct. 1, 1917, Vol. 11, No. 1, pp. 1–26. Nine plots, 1 rod square, were established in 1915, and reexamined in 1915 and 1916; 97 additional plots established in 1917, and others examined. In 1918 plots on 5 areas were reexamined, an 80-acre seed-tree tract located in the Wind River Valley, examination made of field tests of seed stored in the duff, and germination tests made in the nursery of stored seed from each station.

Continuing. Seed tree plots and after-cutting-reproduction plots to be initiated on the Oregon Forest.

Assigned to J. V. Hofmann.

Thinning

119. Effects of different degrees of thinning. To determine the comparative merits of different degrees and frequency of thinning on the

growth of the remaining trees in a stand. Seven experiments are now under way in three Districts:

District 1.

(*a*) Western white, western yellow, and lodgepole pines, Douglas fir and western larch—Priest River (Project Mt-1, D-1). Work begun on Deerlodge Forest with yellow pine in 1911. In 1913 a series of $4^1/_2$-acre plots laid off in typical white pine-larch mixture at the experiment station and thinnings of different degrees made. Progress report April, 1914. Another series of plots established in white pine-larch mixture at the Experiment Station in 1914.

Continuing.

Assigned to investigative staff.

District 2.

(*b*) Western yellow pine—Black Hills (Project Mt-1, D-2). Begun in 1906 by Alfred Gaskill, who established nine plots in stands of different ages and densities, and thinned one. Some of these abandoned, others remeasured in 1912 and 1914. In 1909 three plots established, each 50′ × 100′ in size, representing three degrees of thinning; remeasured in 1914 and report submitted.

Continuing. Complete remeasurement to be made in 1919.

Assigned to C. G. Bates.

(*c*) Lodgepole pine—Medicine Bow (Project Mt-2, D-2). Begun in 1909, when eight plots were established, mapped, and variously thinned. Early work summarized in "Lodgepole Improvement Cutting," mss. report, 1911–12. Remeasured in 1914.

Continuing. Complete remeasurement to be made in 1919.

Assigned to C. G. Bates.

(*d*) Lodgepole pine—Medicine Bow (Project Mt-3, D-2). Begun in 1909, when three plots of $^1/_4$ acre each were established in a 30-year-old stand, mapped, and thinned. Partial remeasurement in 1912 (memorandum of Jan. 6, 1914). Complete remeasurement in 1914.

Continuing. To be remeasured in 1919.

Assigned to C. G. Bates.

(*e*) Lodgepole pine—Washakie (Project Mt-4, D-2). Begun in 1911, when three plots 100 feet square were laid out in 50-year-old lodgepole, and variously thinned. Remeasured in 1916.

Continuing. To be remeasured and stem analyses to be made in 1921.

Assigned to C. G. Bates.

(*f*) Douglas fir—Fremont (Project Mt-7, D-2). Initiated 1917.

Continuing.

Assigned to C. G. Bates.

District 4.

(*g*) Aspen—Great Basin (Project Mt-1, D-4). In 1912 four plots were laid out, of which two were transferred to project Fp-1. One plot thinned in 1913, the other in 1914. Seven additional plots established and thinned in 1914. Plots inspected and sprout reproduction recorded in 1917.

Continuing.

Assigned to C. F. Korstian.

MENSURATION

120. Volume, growth, and yield studies. To secure reliable data as to the growth, volume and yield of the different species and types of forest, as a basis for the proper handling of timber sales, management of the forests, and determination of damage caused by fire, trespass, etc. Particularly to standardize (1) the methods of collecting volume table data and (2) the form of the final volume table.

The work dates from the beginning of the Division of Forestry (1886) but has been most active within the last seven years. For 107 species there have been prepared 755 volume tables, 552 growth tables, and 80 yield tables, together with a large number of tables of form, height, etc. In addition, there were established over 300 permanent sample plots in nearly all the forest regions of the United States for the study of the growth and yield of stands.

Assigned to District investigative and local Forest staffs in cooperation with the Section of Computing, Washington office.

There are now 14 studies under way in seven Districts:

District 1.

(*a*) Douglas fir—Priest River (project ME-1, D-1). Progress report 1917.

Continuing.

(*b*) Lodgepole pine (project ME-2, D-1). Begun in 1912. Volume and yield data published in D. A. Bulletins 154 and 234. No work done in 1915–18. Deerlodge Forest and Dry Gulch Expt. Area.

Data will be gathered as opportunity offers in connection with other work.

(*c*) Western yellow pine (project ME-3, D-1). Begun in 1912, when 3,000 tree measurements were submitted for volume tables. Permanent plot established at Priest River, 1916. Volume table, Custer Forest, 1918.

Continuing.

District 2.

(*d*) Lodgepole pine (project ME-1, D-2). Volume study begun on the Arapaho and Medicine Bow in 1911, and Washakie in 1914. Local tables prepared for first two Forests. In 1915 a general board foot volume table, based on about 2,000 trees from the three Forests, was issued.

(*e*) Western yellow pine (project ME-2, D-2). Begun in 1911 on the Montezuma and later extended to the San Juan.

Project open for collection of data on larger trees.

(*f*) Engelmann spruce (project ME-4, D-2). Begun in 1912 and carried on on several Forests. A tentative volume table issued.

(*g*) Western yellow pine—Black Hills (project ME-5, D-2). Begun in 1914.

(*h*) Douglas fir—Pike, Rio Grande (project ME-6, D-2). Proposed in 1916, but little progress has yet been made.

District 3.

(*i*) Western yellow pine, Douglas fir, Engelmann spruce, white fir—Fort Valley and various Forests (project ME-1, D-3). Begun for yellow pine in 1911, Fort Valley. Proposed method of determining growth in uneven-aged stands found unsuitable for western yellow pine,

1913. Studies of the other species begun 1915. Volume table for Douglas fir constructed 1917, Alamo. Publication: "The Use of Frustum Form Factors in Constructing Volume Tables for Western Yellow Pine in the Southwest," by C. F. Korstian. Proc. Soc. Amer. Foresters, July, 1915, Vol. 10, No. 3, 301–14.

District 4.

(*j*) White, Douglas and Alpine firs, and Engelmann spruce (project ME-3, D-4). Begun in 1917 with study of rate of growth and yields, particularly with reference to association of these species with aspen.

District 5.

(*k*) Western yellow pine; second-growth in the Sierra Nevada (project ME-1, D-5). Begun 1913, when 33 sample plots were measured on the Tahoe, Sequoia, Sierra, and Stanislaus Forests, and about 85 complete stem analyses of sample trees made. Field work completed in 1914 and progress report submitted. Final report on "Characteristics and Yield of Second-Growth Yellow Pine in the Sierra Nevada," by W. H. Gallaher, submitted 1915. (See also under Tree Studies.)

Field work completed. Publication as a bulletin postponed pending further revision.

(*l*) Rate of growth of chaparral in southern California (project ME-3, D-5). Begun in 1912, Converse.

Final report under preparation.

District 6.

(*m*) Douglas fir (project ME-161, D-6). Three plots for study of growth of stands as affected by site and density, established 1910 on the Cascade; 4 in 1911 on the Siuslaw; and 8 in 1914 on the Columbia (3 of which were burned in 1915). Cascade plots remeasured 1915 ("Five years' Growth on Douglas Fir Sample Plots," by T. T. Munger. Soc. Amer. Foresters, Proceedings, Oct., 1915, Vol. 10, No. 4, 423–5), Siuslaw plots remeasured 1916 (manuscript report).

Cascade plots to be remeasured in 1915, the Siuslaw in 1921, and the Columbia in 1919. Additional plots will be established as opportunities arise.

(*n*) Sitka spruce, growth and yield—New (project ME-148, D-6).

121. Permanent sample plots (project ME-3, D-8; formerly Z-6, D-8, Special Studies). To obtain accurate figures on growth and yield, reproduction, and other silvicultural characteristics.

Establishment of permanent plots begun in 1904 under direction of H. S. Graves and George Hewitt Myers, and continued in 1905, 1906, 1913, 1914, and 1915. Periodic remeasurements, usually at 5-year intervals. Over 300 plots for study of growth, yield, and silvicultural features are now under observation, together with about 200 square rod plots for study of reproduction. Species studied include white, scrub, loblolly, shortleaf, and longleaf pines, spruce, cypress, mixed hardwoods, and mixed hard and soft woods. Plots in this project are located in New Hampshire, Vermont, Massachusetts, Connecticut, New York, Pennsylvania, Maryland, Virginia, South Carolina, Florida, Louisiana, and Arkansas. Plots in Connecticut, New York, Pennsylvania, Maryland, and part of those in New Hampshire and Vermont have been turned over to State and college agencies for subsequent remeasurement and observation.

Periodic remeasurements to be continued by the Forest Service and the States (in the cases in which the work has been transferred to them). The following bulletins are to be prepared in the Forest Service on the basis of past measurements: "The Growth of White Pine" and "The Growth of Loblolly Pine."

Assigned to W. D. Sterrett, W. B. Barrows, and State and College forestry departments.

122. Standardization of volume tables (project ME-7, D-1, 2, 3, 4, 5, 6, 7, 8).

Douglas fir tree measurements have been sent in to the Washington office by Districts 1, 2, 3, 4, 5, and 6. Preliminary work on the data from Districts 2, 3, and 5 has been done, and work is now under way for the other Districts. A comparison of the form quotients from different Districts indicates that while sizes differ the forms are so similar that data from several widely separated localities can be combined in one taper table, which can then serve as a basis for a "standard" volume table.

Taper tables for Douglas fir will be finished in accordance with the working plan, and other species of importance will be taken up one by one.

Assigned to W. B. Barrows, in cooperation with the Districts.

PROTECTION

Animals

123. Recuperation of different tree species from injury by grazing (project Pa-1, D-3). To determine definitely the time and character of the injury and the ultimate economic effect of the injury upon tree growth.

Work begun on Coconino in 1910. Additional records established in 1914 and 1915. Records have been maintained on saplings since 1914. These records are intended to supplement the more comprehensive study carried on by Mr. Hill under the Office of Grazing.

Continue records; plots to be reexamined every five years. The saplings measured in 1914 to be remeasured and rephotographed in 1919.

Assigned to officer in charge of the experiment station and local force on the Forest.

124. Control of rodents (project Pa-1, D-5).

Work begun in 1913. Poisons and traps set out on planting sites, but ineffective. Cooperation with the Biological Survey in winter of 1914 and during 1916. Effective measures worked out and plot of 80 acres established as a check. Reports on the pack rat and seed supply, and pack rat and natural reproduction submitted. Rats almost eliminated. Publication: "The Pack Rat as an Enemy of Natural Reproduction on the Angeles National Forest," by E. N. Munns. Jour. Forestry, April, 1917, Vol. 15, No. 4, 417–23.

Discontinued with the abandonment of the Converse Experiment Station.

Data being compiled.

Assigned to E. N. Munns.

Diseases

125. Causes of tree diseases and methods of prevention and control. (See also the projects listed under Bureau of Plant Industry, Investigations in Forest Pathology.)

Many fungi responsible for the decay of the different species have been discovered and described. The following 14 studies under the direction of Dr. James R. Weir, Forest Pathologist are now under way:

District 1.

(*a*) Diseases of western white pine (project Pd-2, D-1). Begun 1912.

(*b*) Diseases of western hemlock, grand fir, alpine fir (project Pd-3, D-1). Begun 1911. Publication: "A Study of Heart-rot in Western Hemlock," by J. R. Weir and E. E. Hubert, Dept. of Agr. Bulletin 722, 1918; "The Influence of Thinning on Western Hemlock and Grand Fir Infected with *Echinodontium tinctorium*," by J. R. Weir, Jour. Forestry, Jan. 1919, Vol. 17, No. 1, 21–35; Mss. report: "Some Considerations Pertaining to the Diseases of Western Hemlock and Grand Fir as Affecting Forest Management," by J. R. Weir, 1914.

(*c*) Diseases of western red cedar (project Pd-4, D-1). Begun 1914. Publication: "*Keithia Thujina*, the Cause of a Serious Leaf Disease of the Western Red Cedar," by J. R. Weir, Phytopathology, Aug. 1916, Vol. 6, No. 4, 360–3.

(*d*) Diseases of Lodgepole pine (project Pd-5, D-1). Begun 1915.

(*e*) Diseases of western larch (project Pd-8, D-1). Begun 1915.

(*f*) Forest tree rusts (project Pd-6, D-1). Begun 1916. Publication by J. R. Weir and E. E. Hubert in Phytopathology: "Recent Cultures of Forest Tree Rusts" and "Pycnial Stages of Important Forest Tree Rusts," April, 1917, Vol. 7, No. 2; "Notes on the Overwintering of Forest Tree Rusts," Feb. 1918, Vol. 8, No. 2; "Notes on Forest Tree Rusts," March 1918, Vol. 8, No. 3. In Amer. Jour. Bot.; "Observations on Forest Tree Rusts," June, 1917, Vol. 4, 327–35.

(*g*) False mistletoe (project Pd-7, D-1). Begun 1916. Publications by J. R. Weir: "Mistletoe Injury to Conifers in the Northwest," Dept. of Agr. Bulletin 360, 1916. "Larch Mistletoe," Dept. of Agr. Bulletin 317, 1916. "Some Suggestions on the Control of Mistletoe on the National Forests of the Northwest," Forestry Quarterly, Dec. 1916, Vol. 14, No. 4, 567–577.

(*h*) Forest tree disease surveys (project Pd-9, D-1). Begun 1916. Publications: "Forest Disease Surveys," by J. R. Weir, U. S. Dept. of Agr. Bulletin 658, 1918.

District 3.

(*i*) Effect of mistletoe on growth and seed production of western yellow pine (project Pd-3, D-3). Begun 1910. Progress reports 1913, 1914, and 1915. Report on "Effect of Mistletoe on the Growth of Western Yellow Pine," by W. H. Long and C. F. Korstian, 1917.

Continuing.

Assigned to Ft. Valley Experiment Station in cooperation with Dr. W. H. Long, District Pathologist.

(*j*) Decadence of mature western yellow pine (project Pd-4, D-3). Begun 1910. Progress reports, 1913, 1914.

Continuing.

Assigned to Ft. Valley Experiment Station.

(*k*) Study of heart rots in connection with timber sale practice (project Pd-5, D-3). Begun 1914. Progress report 1915.
Continuing.

Assigned to Dr. W. H. Long.

District 5.

(*l*) Pathological investigations (project Pd-2, D-5). Begun 1914. Progress report 1917. Publication: "Forest Pathology in Forest Regulation," by E. P. Meinecke, Dept. of Agr. Bulletin 275, 1916.

Continuing.

Assigned to Dr. E. P. Meinecke, Forest Pathologist.

District 6.

(*m*) Damping off (project Pd-1, D-6). Begun 1916. Progress report 1917.

Continuing.

Assigned to investigative staff.

(*n*) Pathological study of Douglas fir on the Cascade Forest (project Pd-161, D-6). Begun 1917. Progress report 1917.

Continuing.

Assigned to Dr. E. P. Meinecke and D-6 investigative staff.

Fire.

126. Development of a scientific basis for rating forest fire hazard and liability (project Pf-1, D-1, 2, 3, 4, 5, 6, 8).

Tentative method for rating hazard and liability drawn up on basis of detailed study of records in Districts 1 and 6. Collection of detailed individual fire reports undertaken in all Districts. Work interrupted by the war.

Detailed study of records in the other Districts, and preparation of final scheme for rating fire danger. Collection of detailed reports on individual fires to be continued in all Districts as basis for revision of ratings in future.

Assigned to W. N. Sparhawk in cooperation with District officers.

127. Relation of meteorological conditions to forest fire hazard and fire protection, with especial reference to the prediction of danger periods and the behavior of fires under given conditions (project Pf-2, D-1, 2, 3, 4, 5, 6, 8).

General survey of weather conditions in the different Districts made, and National Forest area tentatively divided into climatic groups; tentative specifications of dangerous weather conditions drawn up for use of Weather Bureau in forest fire warning service. Experiment stations in several Districts have collected data on relation between inflammability and weather conditions. Studies of rate of spread carried on for two years at Feather River Station. Work interrupted by the war.

Data to be obtained where possible in connection with fire hazard study.

Assigned to W. N. Sparhawk and Experiment Stations in Districts 1, 2, 3, 5, 6.

128. Principles underlying methods of fire protection (project Pf-3), all Districts.

Considerable administrative work has been done in all Districts in developing special equipment. Some studies, such as lookout problems, made in several Districts.

Continuing.

Assigned to District and Forest officers.

129. **Light burning (project Pf-3 (*b*), D-5).** To determine the real value of light burning as a protective measure, the cost and its effect upon the cash value of merchantable and potentially merchantable timber, and on the future of the forest.

Experimental burning done on suitable areas in 1911, and observations and further experiments in subsequent years. Publication: "Light Burning at Castle Rock," by S. B. Show, Proc. Soc. Amer. Foresters, October, 1915, Vol. 10, No. 4. Study of light burning in relation to insect infestation made. Progress report on later work in preparation.

Continuing.

Assigned to S. B. Show.

130. **Smoke visibility (project Pf-3 (*c*), D-6).** To determine (1) distance at which small fires may be seen and how affected by size of fire, atmospheric and other conditions; (2) distance below range of observer's vision at which fires may be seen under different conditions; (3) relative visibility from high mountain (10,000 ft. or more) and ordinary (5000–7000 ft.) lookouts.

Begun in 1917.

Continuing.

Assigned to District office.

131. **Determination of relative amounts of fire damage in different types of forest in different regions (project Pf-4, D-6).**

Study of extent of damage and recovery of injured trees in yellow pine type made on Deschutes Forest in 1915–16. Examination made in 1917.

Continuing.

Assigned to District and Forest officers.

132. **Elimination of static electricity from grounded telephone wires (project Pf-7, D-8).**

Begun as a project in 1916, after some preliminary studies had indicated probable source of static. A telephone line was chosen for study and a topographic map made of entire route. Tests made in 1917 developed equipment by means of which static was absolutely reduced on the experimental line about 50 per cent, without interference with service. Progress report 1917.

Continuing 1–2 years.

Assigned to R. B. Adams, Telephone Engineer.

Insects

133. **Silvicultural methods for the control of the gypsy and brown-tail moths (project Pi-1, D-8).**

Begun in 1913. Twenty-nine sample plots established. Publication: "Control of the Gypsy Moth by Forest Management," by Willis Munro, Dept. Agr. Bulletin 484, 1917.

The sample plots are to be reexamined periodically. In some cases seedlings will need further assistance by the removal of sprouts. Large

trees left should in some cases be removed as soon as desired young growth has established itself beneath them.

Assigned to Forest Service, in cooperation with Bureau of Entomology, W. Munro in charge.

TREE STUDIES

134. **Western white pine (project TS-1, D-1).** Preparation of monograph bulletin.

Begun as a project in 1912. Up to and including 1912, over 4000 tree measurements for volume, and 230 plot measurements for yield had been secured on five Forests. Report on "Western White Pine Seed Distribution" submitted by Mr. Brewster in 1913. Field work on project practically completed in 1913 and preliminary draft of bulletin by F. I. Rockwell submitted 1914. Supplementary field work done and data compiled in 1914–15. Second draft of bulletin submitted 1917. Publication withheld until studies of other phases of the management of western white pine are made. Publication: "Growth of Western White Pine and Associated Species in Northern Idaho," by J. A. Larsen, Jour. Forestry, Nov., 1918, Vol. 16, No. 7, 839–40.

Publication of bulletin postponed for addition of material on other phases of management, for which further field work is required.

135. **Western larch (project TS-2, D-1).** To secure data on the characteristics, distribution, growth, yield, management, and uses of western larch.

Begun as a project in 1916, although data collected in connection with previous projects were utilized. A yield study on the Blackfeet Forest was completed in 1917. Progress report 1917. Publication: "Silvical Notes on Western Larch," by J. A. Larsen, Proc. Soc. Amer. Foresters, Oct. 1916, Vol. 11, No. 4, 434–40.

One year's work remains to be done, but assignment is indefinite.

136. **Jack pine (project TS-4, D-2).** Bulletin on economic and silvicultural importance and management.

A large amount of data secured before 1911 in extensive studies in the Lake States, by L. L. White, H. H. Chapman, J. St. J. Benedict, and others. Further field work in the Lake States, by W. D. Sterrett, 1917. Dept. of Agr. Bulletin entitled "Jack Pine," by W. D. Sterrett, in press.

Completed. Publication pending as Dept. of Agr. bulletin.

Assigned to W. D. Sterrett.

137. **Silvical leaflets (project TS-10, D-8).** To bring together in brief form the available silvical information regarding American forest trees.

Begun in 1907. Silvical leaflets for 53 species have been published. Material available for 16 additional species. No leaflets prepared in 1913–18.

Additional leaflets to be prepared on basis of material on hand. Publication by groups of species, as farmers' bulletins, under consideration.

Assigned to Washington office in cooperation with the Districts.

138. **Oaks of the eastern United States (project TS-12, D-8).** Bulletins on the economic and silvicultural importance of the different species of oak as a basis for management.

Begun in 1916. Field work completed in 1917. First draft of bulletin on "Utilization of Oak," completed in 1919.
Silvicultural bulletin on the oaks to be prepared in 1920.
Assigned to W. D. Sterrett.

139. **Black walnut (project TS-302, D-8).** Bulletin on distribution, silviculture, and management.
Field work done by F. S. Baker in 1918, in connection with study of production of black walnut timber for war use. Report on "Black Walnut: Its Growth and Management," prepared by Mr. Baker for publication as a Dept. of Agriculture bulletin.
Completed. Publication pending as Department of Agriculture bulletin.
Assigned to F. S. Baker.

140. **Western yellow pine (project ME-1, D-5).** Second growth yellow pine in the Sierra Nevada (see also under Mensuration).
Begun as an ME project in 1913. Field work completed 1914 and progress report submitted. Final report on "Characteristics and Yields of Second-grown Yellow Pine in the Sierra Nevada," by W. H. Gallaher, submitted 1915.
Publication of report as a bulletin postponed pending further revision.
Assigned to S. B. Show.

TYPES.

141. **Meterological study of forest types (project T-1, D-1, 2, 3, 5).**

District 1.

(*a*) Begun 1911, completed 1916: Final report on "Climatic Study of Forest Types," by J. A. Larsen, submitted 1918.
Assigned to J. A. Larsen.
Completed.

District 2.

(*b*) Begun as a project in 1914 in cooperation with the Weather Bureau, although actually a continuation of old project M-1, 1910–12. Final report on "Forest Types of the Central Rocky Mountains in Relation to Environmental Conditions," by C. G. Bates, submitted 1919. Publication: "Climatic Characteristics of Forest Types in the Central Rocky Mountains," by C. G. Bates. Proc. Soc. Amer. Foresters, Jan., 1914, Vol. 9, No. 1, 78–94.
Assigned to C. G. Bates.
Completed.

District 3.

(*c*) Begun 1916. Instruments installed at four stations, at which climatological and phenological records have been carried on continuously. Soil moisture samples taken monthly through the growing season of 1918, and sent to Bureau of Soils for chemical and mechanical analysis. In 1918, plants of nearly all conifers of the San Francisco Mountains were potted and records begun on relative rate of water loss of different species and of same species on different sites; also effect of soil upon root development and moisture requirement. Experimental planting of all the species in all the forest types. Report on

"Factors Controlling the Distribution of Forest Types," by G. A. Pearson, submitted 1919. Publication: "A Meteorological Study of Parks and Timbered Areas in the Western Yellow Pine Forests of Arizona and New Mexico," by G. A. Pearson. Monthly Weather Review, Oct., 1914, No. 10, 1615–29.

Instrument records to continue until December 31, 1919. Intensive plant studies to concentrate upon western yellow pine. Study to be directed as soon as possible to solution of problems of forest management as applied in marking policies. Preliminary report now in preparation.

Assigned to G. A. Pearson.

District 5.

(*d*) Begun in 1913, when three meteorological stations were established between 2700 and 7400 feet elevation; these discontinued in 1914, with exception of the station at 2700 feet, and four new established on south slopes at 4000, 5000, 6000, and 7000 feet. In 1915 corresponding north slope stations established. Porous cup atmometers operated at each station. Observations of air and soil temperature and weekly soil moisture determinations made at each station. The station at 2700 feet discontinued in 1916. Data are now being compiled.

Additional field work to be done and final report made in 1919.

Assigned to E. N. Munns.

142. Bear clover (project T-2, D-5) and brushfield (project T-3, D-5) types. To determine extent and distribution of bear clover and brushfields of northern California, their cause, composition, and characteristics; value and use, if any; effects of fire and grazing; character and rate of replacement by timber through natural reproduction; and possibilities of encouraging or securing reproduction of commercial tree species by artificial means.

(*a*) Bear clover.

Begun on the Eldorado, Sequoia, and Stanislaus Forests in 1912. Publication: "Bear Clover," by J. A. Mitchell, Jour. Forestry, Jan., 1919, Vol. 17, No. 1, 39–43.

Assigned to J. A. Mitchell.

Completed.

(*b*) Brushfields.

Begun on the Klamath Forest in 1910, Trinity 1911, Lassen and Shasta 1912, and California, Eldorado, Plumas, Tahoe, and Sierra 1913. Final report, "The Brushfields of California," by S. B. Show, submitted 1919. Publication: "Reforestation of Brush Fields in Northern California," by R. H. Boerker. Forestry Quarterly, March, 1915, Vol. 13, No. 1, 15–24.

Assigned to S. B. Show.

Completed.

143. Forest regions of the United States (project T-2, D-8). (Formerly project Z-1, D-8.)

A map showing natural forest units has been prepared and will be published, with descriptive text, by the Office of Farm Management, as a part of the Agricultural Atlas series.

Project will be closed with the publication of the map.

Assigned to Raphael Zon.

INVESTIGATIONS AT THE FOREST PRODUCTS LABORATORY

MECHANICAL AND PHYSICAL PROPERTIES AND STRUCTURE OF WOOD

Mechanical properties

144. Mechanical properties of woods grown in the United States (project L-124.

The broad project of determining the mechanical properties of woods grown in the United States has been under way for some 15 years. Over 500,000 tests have been made on some 130 species. Such tests form a basis for the comparison of species, the choice of species for particular uses, and for the establishment of correct working stresses. Approximately 150,000 of the 500,000 tests had as their primary object the comparison of the properties of American woods (L-124), about 200,000 the determination of the best methods of kiln drying species particularly for aircraft use (L-221), and the remaining 150,000 included studies of plywood (L-225), studies of the effect of preservative treatment on strength (L-7), tests of airplane parts and other commercial forms, cross-grain investigations (L-228-4), etc. About two-thirds of all mechanical tests made can be used for the purpose of comparing the properties of species. During 1917, 1918, and the first half of 1919 a total of 8770 tests were made. Of these 5834 were on green material and 2936 on air-dry material. The following species were tested:

Honey locust	Goldenleaf chinquapin	Limber pine
California black oak	Cascara buckthorn	Mexican walnut
California laurel	Pacific dogwood	Pinon
Black walnut	Common cottonwood	Gambel oak
Lodgepole pine	Pecan (hickory)	Alligator juniper
Blue gum	Persimmon	Alligator pine
Canyon live oak	Sugarberry	White fir
Madrona	Black willow	White elm
Western black willow	Tupelo (cotton gum)	Red oak
Pale elder	Aspen	Redwood
		Red fir

Practically all applicable project L-221 data obtained to date has been resummarized for use in project L-124. A number of publications have been issued, the most inclusive being U. S. Dept. of Agr. Bulletin No. 556, "Mechanical Properties of Woods Grown in the United States."

Tests are now under way on air-dry redwood and red fir. Tests will also be made on the following species: mangrove, blackwood, Florida buttonwood, mastic, gumbo limbo, pigeon plum, Paradise tree, inkwood, black ironwood, garber stopper, golden fig, fustic, poisonwood, Cuban pine, apple, and such other species upon which we have no data, as opportunity offers for the collection of material. Summarize applicable project L-221 data as this becomes available. But little additional time will be required for this work. Miscellaneous: Prepare manuscript for publications as follows:

"Factors Influencing the Strength Tests of American Woods," "The Influence of Position of Growth Rings on the Strength of Spruce."

145. Tests to determine the strength of wooden beams under continuously applied loads (L-14).

A series of tests on longleaf pine have been completed and the data partially analyzed.

Analysis of the data and preparation of report. A working plan for an additional series of tests will be prepared and if possible work will be continued.

146. Strength of timbers in structural sizes with special attention to grading rules. Strength tests of longleaf pine in structural sizes (L-184).

A large amount of testing on structural timbers of the various qualities commonly found on the market has been done for the purpose of establishing grading rules. These data in conjunction with the tests made on small clear specimens furnish a basis for determining safe values for use in designing timber structures. Grading rules for structural timbers of our two most important coniferous species, southern yellow pine and Douglas fir, have resulted primarily from these tests and studies, and have been adopted by lumbering and engineering associations. A number of articles and bulletins have been published, including Forest Service Bulletin No. 108, "Tests of Structural Timbers." Testing work both on large timbers and on minor specimens cut from them has been completed and the data have been analyzed.

Complete report or article for publication.

147. Strength tests on Alaskan grown timbers in structural sizes (L-189).

Several mine props and caps tested. If Alaskan grown timbers prove suitable for mine use the necessity of shipments from the Northwest will be obviated.

Twelve air-dry timbers and 480 minors of Alaska spruce are to be tested.

148. Tests of green and air-dry Douglas fir bridge stringers to be graded by the New Grading Rules for Douglas Fir (L-197).

Working plan written and several tests made on stringers. These tests will show how the density rule for Douglas fir timbers checks with the actual strength of the timbers. This is an extension of the series of tests on Douglas fir timbers of structural sizes.

Collect material and make tests on approximately 74 stringers and 1776 minors.

149. Strength tests of hemlock in structural sizes (L-211).

Material collected and tests on green material completed. Tentative grading rules prepared on basis of tests made.

Tests to be made on air-dry material, final grading rules to be formulated, and report to be prepared. Miscellaneous: Construct and perfect machine for determining proportion of summerwood in southern yellow pine and Douglas fir.

150. Building codes with reference to timber for structural purposes.

Previous investigations of building codes have shown a wide variation in the working stresses allowed for the same structural timbers in various cities. Milwaukee, Minneapolis, and St. Paul have been visited, and architects, engineers, and city officials consulted concerning the use of timber and building codes. Tables of safe design figures have been prepared for the use of engineers and architects and have been incorporated in the building codes of many cities.

Visit important cities of the United States and compile reports and suggestions.

151. Effect of commercial preservative processes on the strength of structural timbers (L-7).

One series of tests has been made on southern yellow pine and several on Douglas fir. Tests have recently been completed on green Douglas fir stringers treated by a new process developed on the Pacific Coast. Bulletin and several articles published.

The 4″ × 16″ × 4′8″ Douglas fir timbers treated by the boiling process which are now seasoning at the Madison Laboratory are to be cut up into minor specimens and tested. A report on the work will be prepared.

152. Douglas fir (L-7a and 7c).

Considerable data have been collected on both the steaming and boiling processes.

(1) Steaming process. Make tests on 30 air-dry timbers 8″ × 16″ × 16′ (natural and treated) and 750 minors; (2) boiling process. Make tests on 32 air-dry timbers 8″ × 16″ × 16′ (natural and treated) and 768 minors.

Assigned to Seattle Laboratory.

153. Tests of poles (L-31a, 31b, and 31c).

All tests complete. Bulletin published. Final report in progress will cover all major and minor telephone pole tests made by the Forest Service.

Complete report.

Assigned to Seattle Laboratory and Forest Products Laboratory.

154. Utilization of National Forest timbers (L-215).

Western yellow pine and white fir railroad ties obtained from the Atchison, Topeka & Santa Fe Railroad Company have been tested.

Complete analysis of test data and prepare report on tests and inspection trip for District 3.

Assigned to Forest Products Laboratory.

155. Effect of defects on the mechanical properties of wood. Limits of spiral grain: Influence of spiral grain on strength properties (L-228-4).

Reports prepared giving results of tests on kiln-dry Sitka spruce and Douglas fir. This project applies especially to airplane stock. It was found that several members could contain certain defects properly placed without loss in strength. Cooperation with the Bureau of Construction and Repair. Effect of advance decay and discoloration by wood-rotting fungi on the mechanical properties of airplane wood (L-243).

Bureau of Plant Industry, Investigations in Forest Pathology, cooperating with the Forest Products Laboratory, conducted tests on woods used in airplane construction at the testing laboratory of the University of California.

Prepare working plan for tests on ash. Conduct investigation and write report, and possibly article for publication giving effect of cross grain on strength of ash. Review manuscript to be prepared by Bureau of Plant Industry, Investigations in Forest Pathology on investigation. Miscellaneous: Prepare manuscript for publication showing the effect of cross grain on the mechanical properties of Sitka spruce, Douglas fir, and white ash, when tests of latter are completed.

156. Vibration and fatigue tests of wood (L-229).

A few preliminary tests were made under project (L-225-1) in which the wood fibers were subjected to reversals in stress. A machine is nearly completed and preliminary experiments are under way to determine the laws governing the natural period of vibration of wood. This preliminary work is a prerequisite to studying the effect of vibration on the mechanical properties.

Complete preliminary tests to determine most satisfactory method of testing. Prepare working plan, conduct investigation, and write report on effect of vibration on strength.

157. South American woods

Tests on a few South American woods have been completed and a preliminary summary of the data has been made. The air-dried specimens have been examined and the soaked specimens are being examined for decay. A very high percentage of the material is decayed and will not afford reliable strength data.

Complete examination of soaked specimens and record this information with the strength data. It may be found desirable to resummarize the strength data so as to eliminate the results obtained on decayed specimens. Additional work on South American woods is desirable.

158. Influence of drying and steaming on the strength of wood (L-221).

Influence of drying and steaming on the strength of airplane stock (L-221-1).

The specifications for kiln drying airplane stock prepared for the Army and Navy are based largely on the results of tests made under this project (L-221-1). (*a*) Tests were made on the following species: sugar maple, white fir, Douglas fir, white pine, western white pine, Norway pine, bald cypress, eastern spruce, Sitka spruce, noble fir, Port Orford cedar, western yellow pine, yellow birch, black walnut, red gum, African mahogany, Central American mahogany, and yellow poplar. The effect of kiln drying on the strength of airplane woods published as Report No. 68 of the National Advisory Committee for Aeronautics. A number of articles also published. (*b*) Additional material of the following species is available in log form: Douglas fir and bald cypress. This work has been in cooperation with the War and Navy Departments.

L-221-1 (1) Complete reports on work under (*a*).

(2) Make four kiln runs on bald cypress and three kiln runs on Douglas fir.

(3) Test kiln-dried cypress and Douglas fir and also the corresponding matched green and air-dried material. Conduct tests under this project on white ash to be kiln dried for project L-228-4, if possible.

(4) Complete reports embodying results of tests to determine effect of kiln drying on strength.

159. Effect of moisture on mechanical properties of wood (L-240).

Research begun in cooperation with Yale Forest School. Results published in Forest Service bulletin 70 and Circular 108. This work included several species and several properties, but needs to be extended to numerous other species and especially to such properties as drop in impact and work values in static bending. From a recent review of data an equation between moisture and strength has been derived which seems to represent a fundamental natural law. If this

equation proves to be applicable to all species and properties the value of project L-124 will be greatly enhanced.

A study of moisture relations for all strength properties and for a few additional species as well as the determination of the fiber saturation point for all species should be undertaken. Tests on redwood which are now under way will be completed and a report prepared.

160. Bent forms. (*a*) Methods of bending and their influence on strength (L-234).

Relatively large stock (vehicles). Two brief reports prepared based on field study of bending of heavy rims. Apparatus for steaming, boiling, and bending installed and some tests completed on red and white oak.

Report on experiments in bending red and white oak vehicle stock to be completed. A general study should be made of fundamental factors involved in bending heavy or light stock to a severe or moderate extent in order to secure a minimum loss of strength and maximum ability to retain form. Information is needed as to methods of severe bending of material such as artillery rims and more moderate bending such as airplane longerons, as well as a study of methods of bending coniferous woods such as spruce and Douglas fir.

Relatively small stock. Tests on commercial white ash and spruce made to secure preliminary data in connection with the bending of airplane stock such as longerons. A report was issued giving results of these tests.

(*b*) Bending tests of special forms (L-231).

(*c*) Plywood bent forms. Methods of bending (L-225–6).

This project largely in cooperation with War Department.

161. Strength tests. Built-up beams (L-4).

Eleven 8″ × 12″ × 16′ bolted beams were made up of 2″ clear southern yellow pine. These beams, including 1210 minor tests, have been tested and the data have been tabulated. These tests were made in cooperation with the National Lumber Manufacturers' Association. Investigations of built-up construction become more and more important with the increasing difficulty of securing material of satisfactory quality in large sizes.

Complete report on these tests. Additional work on built-up beams desirable.

162. Tests on mechanical efficiency of joints and fastenings in wooden structures (L-9).

Four beams were built up of $2^1/_2$″ × 16″ × 16′ southern yellow pine members and tested.

Complete report of work.

163. Plywood study (L-225). The following series of plywood investigations is conducted in cooperation with the Army and Navy:

(*a*) Strength tests of plywood (L-225–1).

Strength tests have been made of 35 species. These tests supplied information on the variation in strength of different combinations of species, number of plies, and ratio of core to total plywood thickness. Information regarding causes and prevention of the warping of plywood, its bearing strength, and shrinkage, are available but to a more

limited extent. Several reports have been published and an exhaustive report is under preparation.

Working plan to be prepared and tests conducted to determine toughness of plywood, and report to be written. Material for this work now on hand.

Warping tests of plywood. Working plan to be prepared, investigation conducted, and report to be written.

Stiffness of plywood in different directions. Working plan to be prepared, investigation conducted, and report to be written.

(*b*) Strength tests of built-up plywood forms (L-225–2).

Many tests have been made on built-up plywood forms such as airplane engine bearers, wing ribs, and elevator spars. A limited number of tests have been made on plywood as a substitute for linen airplane covering. Several reports have been published.

DeH-4—A DeH-4 airplane wing to be designed, constructed, and tested, using woven plywood. Report to be written.

MF—Plywood for two MF wings to be secured and applied. Covering to be finished with varnish and aluminum leaf, and sent to Naval Aircraft Factory for weathering tests.

DeH-4—Sections of plywood wing to be coated with varnish and aluminum leaf. Weathering test to be conducted and report written.

(*c*) Strength tests of plywood fastenings (L-225–4).

Screw fastening tests completed to determine length and size of screws, as well as spacing and margin for 3-ply wood. Report to be completed.

Plywood bearing—Some tests completed on various series of plywood. Report to be completed.

Manuscript to be completed for publication on the "Mechanical and Physical Properties of Plywood."

164. **Aircraft study (L-228).** This study is being conducted in cooperation with the War and Navy Departments.

(*a*) Strength tests of airplane struts (L-228–1).

Tests have been made on several types of airplane struts. Entirely new and easily applied methods of testing have been developed for use in making inspection tests.

Data to be analyzed from tests of struts of rectangular cross section. Series of streamline tapered struts to be prepared and tested, report to be prepared, and article for publication. Development of Thelen strut to be continued, conducting tests with different end conditions and with streamline members; on completion of development, report to be prepared, and article for publication. Working plan to be prepared and tests conducted on both tapered and untapered fuselage struts with varying ratios of L/r, and report and article to be written for publication.

(*b*) Specifications for airplane parts (L-228–2).

Specifications for Army and Navy to be reviewed and prepared as required.

(*c*) Strength tests of airplane wing beams (L-228–3).

Tests have been made on quite a number of different types of wing beams, and among other things have shown the possibility of built-up and laminated construction for use under most exacting requirements. Apparatus has been designed and constructed for combined loading tests of a U. S. D-9 wing beam. Tests have also been made on dirigible girders. Several reports have been published.

The tests of the U. S. D-9 wing beam and the dirigible girders are to be completed and reports prepared. For the girders, redesign and continue the investigation if necessary; report to be prepared for the Navy. Box beams for maximum strength and stiffness to be designed, using developments of plywood investigation in construction of cheek pieces; a working plan to be prepared, tests conducted, and report written.

Manuscripts are to be completed for publication entitled "Tests on Airplane Parts" and "Wood in Airplane Construction."

165. Tests of manufactured articles (L-248).

(*a*) Mechanical tests on doors (L-248-1).

Mechanical tests on 48 doors of three different types were completed and warping tests on 24 other doors are practically completed.

Report to be completed on these tests. A further series of tests on different types of joints commonly used in door construction should be made.

(*b*) Development of a box testing machine and methods of testing boxes (L-207).

A box testing machine has been developed consisting of a large, hollow, hexagonal drum in which the boxes to be tested are placed. When the drum is rotated the boxes are tumbled about, striking on their corners, edges, sides, etc. By means of this machine the relative strength of various designs can be shown.

Additional testing machines will be developed if found necessary.

(*c*) Tests on packing boxes to determine the relation of thickness of material, kind of wood, strapping, etc., to the size of box and weight of contents (L-207-3).

Tests have been under way for the past seven or eight years on a large number of types of boxes for widely varying uses. Tests during the war were made almost entirely for the War Department. These tests have yielded preliminary data of great value on the general relationships which are the purpose of the project. A large number of articles have been published and a long manuscript entitled "Manual of Wooden Box and Crate Construction" has been completed for publication.

Tests will be continued with particular reference to the development of general laws which will be applicable to specific questions of container design and specifications. The box and crating manual will be published as soon as possible.

(*d*) Tests on fiber and corrugated shipping containers for the improvement of design (L-207-4).

Certain phases of this work are financed by the Ordnance Department. A comparatively limited number of tests has been made on fiber and corrugated shipping containers. Progress reports have been written.

This work will be continued as opportunity offers.

(*e*) Resistance of various species of timber to the withdrawal of nails (L-9*a*).

An article entitled "Tests made to Determine the Lateral Resistance of Wire Nails" was published in the Engineering News Record. No tests have been made on this project for several years. Nail pulling tests were made on hemlock, shipments L-435 and L-436.

Resistance of various species of timber to the withdrawal of nails (L-9*a*) (continued).

Work called for in plan to be completed as opportunity offers, including tests on splices and additional tests on crushing, splitting, and shearing effect of bolts. Report to be completed on tests already made. Tests to be made as opportunity may offer on additional species. Tests ultimately to include all species collected under Project L-124.

Physical properties

166. Fundamental laws of drying wood (L-134).

Investigations of various phases of the laws of drying wood have been under investigation for the past 15 or 20 years and have resulted in numerous articles and bulletins. Much of the work under the following project, "The kiln drying of various species of wood," has aided in the development of fundamental drying laws.

(*a*) Investigation has been outlined and two years' work done on the rate of transfusion of moisture through wood and influences that might increase it. Discontinued during war.

(*b*) Some work has been done on the effect of preliminary treatment upon subsequent drying and working of wood, and a progress report has been written.

Three reports will be written under this project prior to July 1, 1920. Work on "Fundamental Factors Affecting Shrinkage," "Comparative Rates of Drying in the Three Coordinate Directions of Various Species," and similar problems will be undertaken as soon as possible.

Work already done, as outlined under (*a*) above, will be assembled in form of a progress report.

Work, as outlined under (*b*) above, will be reviewed and progress report prepared. Additional work will be initiated.

167. Experiments in kiln drying different species of wood (L-142). Army or Navy funds are used as the work requires.

Work under this project has resulted in the development of a dry kiln in which it is possible to regulate closely temperature, humidity, and circulation, the factors on which satisfactory drying depends. Two types of this kiln, one adapted to slowly drying refractory hardwoods, the other to rapidly drying softwoods, have been invented and patented for the free use of the public. A great deal of progress has been made in working out proper methods of drying for the several species of hardwood and coniferous timbers. A large number of articles and bulletins covering the results of the work have been published.

This study now includes various phases of kiln drying as indicated in detail under the following headings:

(*a*) Six kiln runs have been made on heavy oak and hickory vehicle parts in cooperation with large manufacturers, resulting in information which has been used in cooperation with about 24 manufacturers in the drying of green oak stock at their plants. A shipment of 29 southern swamp oak logs has been received for further experimental work at the Laboratory.

Four additional runs will be made in laboratory kilns to determine treatment required for successfully drying the more refractory species of oak, checking of recommended schedule, and possibilities of increasing drying rate. Further cooperation will be undertaken with vehicle manufacturers in improving present commercial practice.

(*b*) Six inspection trips have been made to ascertain typical commercial methods of seasoning various wooden products.

A definite policy of cooperation will be drawn up with representative concerns in the study of different types of commercial kilns with the view of definitely determining the possibilities and limitations of each type for a given class of drying. One kiln run will be made under commercial conditions in each of three types of kilns—ventilated, blower, and condenser. Actual figures will be collected as to both costs and losses involved in the ordinary practice of air-seasoning as compared with kiln drying.

(*c*) Kiln runs have been made on sugar pine, Douglas fir, red fir, white fir, ironwood, wild lilac, and dogwood.

Reports will be completed on these species. Additional study will be made of kiln drying miscellaneous hardwoods as occasion demands.

(*d*) Preliminary study has been made of the comparative efficiency of the water spray and steam jet condenser kiln in heat consumption in connection with kiln drying.

One additional progress report will be added to complete the investigation.

(*e*) Ninety-eight kiln runs have been made on various species under consideration for airplane construction to assist in the determination of the effect of kiln drying on the mechanical and physical properties. Five inspections have been made at airplane factories to ascertain practices. One publication prepared for the National Advisory Committee for Aeronautics.

Additional kiln runs will be made on yellow poplar and Philippine mahogany. One publication for aeronautical journals entitled "The Drying of Propeller Woods" will be prepared during the year.

(*f*) Two inspections have been made of common practice of seasoning artificial limb stock at request of Surgeon General, U. S. Army. Reports thereon added to files. Shipment of willow blanks to laboratory from cooperating firm for experiments in kiln drying. Two kiln runs completed.

One kiln run will be made to complete tests in the laboratory kilns and a final report will be written on the investigation.

(*g*) The study of kiln drying of treenails originated in a request from the Emergency Fleet Corporation and as a result of a field study of wood shipbuilding practice. Two reports have been prepared, one of which was submitted to Emergency Fleet as preliminary recommendation. The Emergency Fleet Corporation furnished a carload of live oak squares to kiln dry experimentally.

Two kiln runs on live oak squares will be made and a final report made to Emergency Fleet Corporation.

(*h*) Laboratory test made of possibility of closing surface checks in bent chair stock by subsequent drying and steaming treatments.

Laboratory report will be prepared.

(*i*) One kiln run made in Laboratory kiln in cooperation with chair manufacturer who has dried matched material according to his usual practice in his commercial kiln to determine effect of kiln drying on color of oak chair stock.

Report will be prepared bringing together the comparative results of the two runs.

(*j*) Material representing nine important Brazilian hardwoods received at Laboratory from Department of Commerce. One preliminary kiln run has been completed.

Three more kiln runs will be made and a report prepared.

(*k*) Plans, tables, and figures to assist engineers in the proper design of the water spray kiln for various commercial requirements are being prepared.

This information will be assembled in the form of a handbook for general distribution.

An indefinite number of kiln runs will be made under this project during the fiscal year 1920. A publication on the "Selection and Conditioning of Wood for Vehicles" will be completed. Work will be started on the effect of kiln drying to bone-dry condition and then allowing reabsorption on the strength and brittleness of wood, as compared with wood dried down to a given moisture content without reabsorption and effect of widely varying conditions during kiln drying on the rate of drying and condition of the wood as compared to drying under uniformly steady conditions.

168. Bending and drying bent furniture stock (L-234-1).

Cooperative study in bending and drying under commercial conditions has been conducted by Laboratory representative at a chair manufacturing plant. Characteristic problems involved have been ascertained and some of the principles involved in bending wood have been investigated.

Report of cooperative study is being prepared.

169. Study of microscopic structure of important woods with special reference to relation of structure to physical and mechanical properties (L-20). This work is carried on under several subheadings, the status and continuance of which are as outlined below. Plans for a study of the nature and properties of "compression wood" are outlined. An article on "Some Defects Found in Airplane Wood" is to be written.

(*a*) *Identification.*—Information has been collected on the identification of several genera of American woods. Over 17,000 specimens submitted by the Service and cooperators were identified in 1918. Special studies of various groups of woods have been made, as, for instance, the work on the identification of woods classified as mahogany; also the separation of Douglas fir and Sitka spruce. A working key covering about 125 species of foreign woods has been prepared. A number of articles and bulletins have been published.

Continuous identification of specimens submitted. Special studies to be made as time permits on the identification of pines, material of which has been collected, and also on oaks and hickories. Each study will furnish material for a publication. A revision for publication of the article on the identification of mahoganies is planned. Government bulletin "Identification of Furniture Woods" is to be prepared.

(*b*) *Fiber Measurement Studies.*—Specimens submitted intermittently. Recently some work has been done on cotton linters.

No work planned.

(*c*) *Resin Studies.*—Partly completed. Most of the material collected. No work has been done on this for about a year due to pressure of war work. Complete study on pines and if possible obtain comparative data from larch and Douglas fir. The results will be presented in form for publication in Journal of Agricultural Research or other Government bulletin.

170. **Penetrance of wood by preservatives (L-22).** Work as outlined to date completed. Article on "Bordered Pits in Douglas Fir" submitted for publication in Journal of Forestry.

Some miscellaneous work will probably be done on the microscopic studies of glue joints in cooperation with the section of preservation.

171. **Mold studies.** Effect of molds on woods used for airplane and vehicle stocks (L-245). Investigation partially complete. Material collected and cultures prepared.

Study of material on hand and preparation of illustrated report for publication in Journal of Agricultural Research or Phytopathology.

WOOD PRESERVATION

172. **Physical and chemical properties of coal tar creosote.** Volatility (L-144-1). Work on this project has been under way for a number of years and results have been covered by a series of articles and Government publications. A further publication on "Coal-Tar and Water-Gas Creosotes" is practically completed.

(*a*) Preliminary calculations indicate that the loss of creosote from treated wood can be expressed in the form of a mathematical equation. The equation must contain some function of the volatility of the creosote, the amount of oil used, and the time and temperature at which the treated wood is held. The data available can not be used because the pieces of wood contained an unknown amount of water. Working plan written.

Sections of wood to be treated and held at various moisture contents and temperatures.

(*b*) Tests are under way to determine the composition of creosote remaining in telephone poles after 22 years of service. Work of drawing conclusions to be continued especially in regard to volatilization of the creosote during service. The manuscript on "Coal Tar and Water Gas Creosotes" will be reviewed and published during the year.

173. **Efficiency of various fractions of coal tar creosote and other preservatives in protecting southern yellow pine from marine wood borers (L-120).** Work on this project has been under way for a number of years and preservatives have been studied that give great promise of improvement in protection from marine borers. Articles covering results have been published.

Recent work in cooperation with the Bureau of Fisheries promises to result in the development of a greatly improved marine preservative.

Prepare plans for work along the lines indicated by results and conduct such work as opportunity affords. Inspect specimens located in Pensacola and Gulfport.

174. **Swelling and shrinking of wood as influenced by various treatments and coatings (L-134-5).**

Information has been obtained upon the effectiveness of various kinds of varnish and other coatings, and various numbers of coats of the same varnish. Improved methods of finishing with varnishes have been developed. A very effective method of preventing moisture changes by the application of aluminum leaf and varnish was developed and demonstrated to the Air Service of the Army, and to the Bureau of Construction and Repair of the Navy Department. The results of this work have been published in a number of journals. A test on the

durability of varnish and enamel coatings exposed to the weather is well under way.

The work is in cooperation with the War and Navy Departments. Durability studies are to be continued and results reported. Search for water-resistant coatings to be continued, especially such as would be suitable for the protection of glue joints in exposed wood work. Study of Forest Service paint problems to be continued.

175. **Inflammability of untreated wood and wood treated with fireproofing compounds (L-179).** Studies have been made upon the relative inflammability of various species of wood. Many methods of fireproofing wood by means of paints, coatings, and impregnations were studied and results have been published. A method of fireproofing shingles and a very effective fire retardent paint have been studied and are under development.

During the year 1917 plans had been made, but no work done, toward a series of tests designed to show the effectiveness of various details of construction in retarding fire.

The fireproofing of plywood for aircraft is to be studied, giving particular attention to the effect of fireproofing materials upon strength and water-resistance of glues and upon wood finishes. Further developments of fire-resisting problems as finances permit, with special stress on fire stops and to improve methods of testing fire-resistance of wood.

176. **Investigations of conditions in buildings which promote decay of timbers used in their construction (L-191).** A general field study has been made of conditions existing in wooden factory buildings with reference to decay and the development of methods of prevention. Articles covering results have been published.

Roof timbers were treated with sodium fluoride and with creosote in cooperation with the Southern Pine Association to be placed in the roofs of several textile mills in New York and New England. A working plan has been prepared covering the study of moisture conditions existing in buildings, but the study has not yet started.

The installation of treated timbers to be completed. Use of treated wood in buildings where decay is a serious difficulty, as in cotton mill and bleachery mill roofs, to be developed.

177. **Use of National Forest timber for ties (L-194).**

Manuscript prepared for publication.

Manuscript to be brought up to date and published.

178. **Experiments with railway crossties in cooperation with the C. M. & St. P. Railway and the Bureau of Standards (L- 213).**

The test tract now contains about 630 ties treated with five different preservatives, and about 200 untreated ties. Four hundred additional ties have been treated and are now being installed. Measurements of electrical resistance of the ties are being made at intervals.

Two hundred additional ties to be treated in the spring of 1920 with a preservative to be decided later. Electrical measurements to be continued.

179. **Durability of treated and untreated wood (L-214).**

About 17 test tracks, 10 pole lines, 14 fence post tests, 6 mine timber tests, 4 piling tests, 2 wood block pavements, in cooperation with various companies, organizations, and individuals are under observation, and

records are being collected from all other available sources. Records of service tests of ties, poles, and posts were published in the Proceedings of the A. W. P. A. and the A. R. E. A. in 1917 and later records of ties in A. R. E. A. Bulletin No. 210, Oct., 1918. Numerous other articles have also been published.

Inspections to be continued as conditions require, and collections of data from other sources to be continued. Cooperation with American Wood Preservers' Association and American Railway Engineering Association to be made use of in publishing data obtained on ties and other timbers. Publication on results of fence post investigations to be prepared.

180. The preservative treatment of poles (L-249). Work was begun about 17 years ago. Methods of treating telephone poles and fence posts were developed which have been generally adopted. A number of reports covering the work have been published.

No work has been done recently, but there is a growing demand for better methods of treatment for poles. A committee of the American Wood Preservers' Association desires cooperation in solving some of the problems now encountered by pole treating companies and users of treated poles, and work of this character may have considerable influence regarding the sale of National Forest species for poles.

Cooperation with the above committee and possibly with the District Forester in District 1 to be developed. Condition of poles known as case-hardening to be studied. Practicability of puncturing poles for non-pressure treatment, and feasibility of pressure treatment to be considered.

181. Laboratory tests on the comparative efficiency of various wood preservatives (L-117). Investigations have been under way for a good many years, the results of which have been covered by a series of articles and Government publications.

A set of specimens for tests on the effect of zinc chloride upon the strength of wood was treated 5 years ago, to be tested in November, 1919. Strength tests on zinc chloride specimens to be made and report prepared.

Efficiency of highly toxic substances dissolved in non-toxic oils. Preliminary work started. Working plan under way. A non-toxic oil to be obtained, if possible, from coal tar creosote, and the various materials usually found in coal tar creosote to be tested for any relationship between their toxicity in oil solutions and the solubility partition in oil and water.

The laboratory study is started on the study of the action of enzymes of timber-destroying fungi on wood. No active laboratory work for the present. Laboratory study to be continued as time permits.

Study of the fire retarding of shingles. Some preliminary work has been done with barium hydroxide as a fire retardent. Also on the standardization of methods of testing. If possible a standard method of testing will be worked out.

182. Experiments on mechanical operative features of pressure wood preserving plants (L-119). An extensive series of tests was conducted on this project a number of years ago, the results of which were published in a Government bulletin.

A detailed study of the treatment of Douglas fir, especially by the Boulton process was being pushed in cooperation with the West Coast Lumbermen's Association when interrupted by the war. No work done during the war.

It is planned to complete and report upon the Douglas fir studies already started, and on the basis of the information thus obtained plan additional work on the treatment of Douglas fir.

LAMINATED CONSTRUCTION

183. Study of glues and gluing (L-157).

Much information has been collected on the principles involved in the preparation of water-resistant glues and the properties of glue ingredients, and a number of excellent formulas for water-resistant glues have been developed. A great amount of information relative to the inspection and use of both water-resistant and animal glues has been obtained and made available to the War Department and the Navy Department. Many thousand tests have been made upon samples of plywood and glue submitted by Government officers and inspectors. Specifications have been prepared for hide glue for propellers, casein for casein glue, waterproof casein glue, and for water-proof plywood, grades A and B. A report dealing with glue in aircraft construction has been published by the National Advisory Committee for Aeronautics, Report No. 66. Much of the work is in cooperation with the War and Navy Departments.

Efforts to develop new glues of greater water resistance and other desirable properties to be continued. Manufacturers' gluing problems to be studied with a view to improving commercial practice and developing the technique of using all glues, but particularly water-resistant glues. Additional information to be obtained on principles involved in gluing, such as the manner in which glue takes hold of different species of wood, regulation of pressure, time, and other factors entering into the production of a glue joint. Properties and uses of marine glue to be studied. Additional study of properties of glue, such as shock resistance, strength, weather resistance, effect on tools, etc., to be made. Gluing of various species of native and Brazilian woods and other woods used in furniture and aircraft construction to be studied. Publication to be prepared from time to time as warranted by results.

184. Study of conditions affecting the manufacture of plywood (L-225-7).

Information has been obtained upon effect of moisture content of veneer upon the finished panel, and studies have been made on effect of amount of pressure upon strength and water resistance of the glue joint. Inspections have been made at many plywood plants and suggestions for improving methods made wherever possible.

Detailed study to be made of all the operations entering into plywood manufacture, with a view to improving commercial practice. This will include a study of gluing of cross grain and fancy veneers and a study of methods of preventing staining of face veneer. Publication on veneer and plywood to be prepared.

185. The influence of shrinkage and swelling stresses caused by atmospheric conditions upon the tensile strength across grain in laminated construction (L-227).

The following species have been manufactured and more or less completely tested: Central American mahogany, African mahogany, red oak, white oak, birch, gum, maple.

Observations, weights, strength tests, etc., in accordance with the approved plan have been made and recorded for permanent record. Preliminary reports covering three of the above species have been prepared: others are under way. The work is in cooperation with the Bureau of Steam Engineering of the Navy.

A complete series of tests will be made for Philippine mahogany and yellow poplar; other species will be added if deemed advisable. Reports will be prepared covering the various steps in conditioning for each species. These reports will then be combined into a species report. A final report covering all species will then be prepared.

186. Influence of atmospheric and manufacturing conditions on airplane propellers (L-233).

The following propellers have been manufactured: 33 from each of seven species; 6 of quartered red oak finished with aluminum leaf coating; and 3 of quarter-inch poplar stock with casein glue. Ten fins of true mahogany and 8 of red gum have been manufactured. All of these have been placed in the conditioning rooms for test. Observations, weights, measurements, etc., in accordance with the approved plan have been made and these have been recorded and plotted for permanent record. Several reports based on information obtained to date have been prepared for publication. Work conducted in cooperation with the Bureau of Steam Engineering of the Navy.

Thirty-three propellers each of yellow poplar and Philippine mahogany are to be manufactured. The work on fins is to be continued until 24 from each of the 9 species have been completed. Reports will be prepared from time to time as data warrants and a final report covering the entire investigation will be prepared when the schedule has been completed.

187. Suitability of laminated construction for various commercial products (L-247).

Laminated shoe lasts have been constructed and tested with very satisfactory results. There appears to be a very good chance of these being put into commercial production. Laminated bowling pins manufactured and tested have given excellent service and are in every way equal to solid pins. Laminated wagon axles, bolsters, hubs, and poles have been made up and tested by placing them out in the weather. Two wagons using laminated stock made up at the Laboratory are now being built for service tests. Laminated poplar hat blocks manufactured at the Laboratory and tried out in service at a local hat blocking establishment are showing satisfactory service. Other articles under investigation are athletic goods, such as Indian clubs and dumbbells, tool handles, and automobile sills. Reports have been prepared on shoe lasts and bowling pins.

It is planned to continue this work on laminated construction, taking up various articles as time warrants. In each case it is the intention to make a thorough preliminary trial of the article, prepare a report on the results, and then if satisfactory try to get commercial production started.

PULP AND PAPER

188. Comparative pulp making tests on various forest woods (L-168). Tests have been run on a large number of species by the soda, sulphate, and sulphite processes. The plans for future work contemplate complete pulping, bleaching, and strength tests by all three of the methods on all American woods such as might be suitable for pulp and paper manufacture. For each process the status and plans are as follows:

(*a*) *Soda Process.*—About 15 species of wood have been pulped by this process using modifications developed at the Laboratory. Four more species are available at the present time. Practically all woods suitable for reduction by this process have been investigated. Such additional woods as may be procured by the Laboratory will be studied.

(*b*) *Sulphate Process.*—Approximately 25 species have been treated using the sulphate process. Work is completed on the proper beating of sulphate pulp. A report has been prepared and submitted to the Nekoosa-Edwards Paper Company, who cooperated with us on this work. Practically all woods suitable for reduction by this process have been investigated. Such additional woods as may be procured by the Laboratory will be studied.

(*c*) *Sulphite Process.*—About 35 species have been pulped by this method. Additional work is outlined on about 14 species. Such additional woods as might be pulped by this process will be studied. Most of the more suitable woods have been pulped. The following are to be pulped: bald cypress, western hemlock, chestnut, sycamore, sugar maple, white oak, Port Orford cedar, Alpine fir, cucumber tree, western larch, basswood, black gum, birch, and jack pine.

(*d*) *Groundwood Process.*—The species of American woods suitable for pulp making under the groundwood process have been tested and the results incorporated in a comprehensive Government bulletin.

(*e*) In connection with tests to determine the suitability of American species for pulp making under the various processes, the processes themselves have been studied intensively with a view to improvements. Improvements of the sulphate and soda processes have been worked out and demonstrated on a commercial scale. Efficient methods for making ground wood pulp which reduced manufacturing waste have also been demonstrated. A series of articles and Government reports have been published. Work will be continued along the same general lines as in the past.

189. Development of methods and specifications for the purchase of pulp wood (L-216).

Considerable data have been gathered to show the relation between cord measure and measurement by weight in the purchase of pulp wood. Observations on the relative merits of the two systems have been published.

Work will be continued as opportunity offers.

190. Utilization of waste bark for tanning purposes (L-238).

The value of waste hemlock bark from pulp mills as a source for tannin for the leather industry has been determined. A report has been prepared and published in various technical journals covering the results obtained by this semi-commercial experimental work.

Make additional mill trials in cooperation with pulp mills and tanneries to collect accurate cost data and other essential information.

191. Study of the suitability of second-cut cotton linters and hull fiber for pulp and paper (L-253).

Experimental laboratory work completed. Reports published in a number of journals.

This work is carried on in cooperation with the Ordnance Salvage Board of the War Department.

Two mill demonstrations will be made where cotton fiber will be pulped on a commercial scale to determine yield, chemical and bleach consumption in order to properly evaluate this stock in comparison with other paper stocks.

192. Study of wood pulp, fiber and paper specialties (L-205).

(*a*) Methods of manufacturing roofing felt from spent hemlock bark have been developed which are now in commercial use.

(*b*) Work has been completed on fiber containers, shrapnel shell plugs, template paper, boxboard, waterproofing boxes, baling and packing papers, and waterproof labels. Further work will be done as occasion demands.

(*c*) Laboratory work completed on desaturating waste roofing and shingle stock to recover the asphalt and paper stock. The cooperators believe that felt as made from desaturated stock is entirely satisfactory. Report will be prepared for publication.

(*d*) Laboratory work practically completed on suitability of primary fiber containers for food products and other commodities as substitutes for metal containers. Two reports now being prepared. Collection of commercial paper containers and special containers, as developed at the Laboratory for testing purposes will be submitted to the Bureau of Chemistry.

(*e*) Routine testing work is done on miscellaneous papers submitted by cooperators. Papers will be tested as they are submitted.

DERIVED PRODUCTS

193. Destructive distillation of hardwoods (L-152-1).

Formerly only beech, birch, and maple were considered suitable for distillation. Tests have been made which show that oak, hickory, ash, and some other hardwoods are also suitable. A series of articles and a Government report have been published. Two species, mesquite and post oak, recently studied to determine suitable location of War Department distillation plants.

No species studies are contemplated except those which may arise from outside sources.

194. Methods of increasing the yields of valuable products in the destructive distillation of hardwoods (L-152-2).

New methods have been developed for the distillation of hardwoods by which it has been possible to increase yields of various products considerably. Results have been published as articles.

This was discontinued during the war but the work on catalyzers has been started again. The study of the effect of catalyzers on the yields of alcohol and acid has been combined with a study of the value of the charcoal as a decolorizer. New methods for distilling the wood-catalyzer mixture have been devised so as to obtain a solid charcoal.

Work along these lines will be continued.

195. Studies of methods for refining hardwood distillates (L-152-3).

A start has been made in the utilization of hardwood tars for other purposes than fuel; for example, as flotation oils. Cooperation with Salt Lake Station of Bureau of Mines on "Flotation Oils from Hardwood Tars" finished and published. Further cooperative work of a more fundamental and detailed character has been arranged with the Seattle Station of the Bureau of Mines.

Continuation of cooperative work with Bureau of Mines.

196. Study of methods and processes used in securing turpentine and rosin by extraction from woods with chemicals (L-159).

This study has been under way for several years and some improvement has been made in extraction processes which have been adopted in commercial practice. Work on this project was discontinued during the war and has not been resumed. It has been found difficult to apply the experimental results in commercial practice.

New problems have lately developed in commercial practice and promising methods for solving them have been thought out so that some work along this line will be started if possible.

197. Study of products obtained from conifers by distillation (L-158).

A detailed study has been made of the composition, properties, and industrial values of wood turpentines and methods developed for their proper refining. Results have been incorporated in a Government bulletin. This work was dropped during the war in order to concentrate on National defense problems.

If the cooperative work with the Bureau of Mines on hardwood tar flotation oils is satisfactory, it is planned to carry out similar work with the pine tars, but it will be some time before this work can be started.

198. Turpentine experiments (L-149).

(*a*) Several series of experiments have been conducted to determine the feasibility of turpentining western conifers. A Government report has been published.

(*b*) Work on production of Venice turpentine from western larch has been started and one year's crop of products has been gathered and tested. Continuation of tapping experiments is planned.

(*c*) War emergency work on production of toluene and isoprene from turpentine finished. No more experimental work along this line is planned, but a report will be prepared for publication.

199. Tests of different methods of turpentining (L-190).

(*a*) As a result of studies undertaken during the last 25 years two radical changes in methods have been developed: first, involving the substitution of the cup and gutter for the box method; second, the introduction of shallow chipping. Numerous articles and bulletins have been published.

(*b*) Comparative tests of the French, American, and a modified American method are now under way.

(*c*) Two years' work in the comparison of three different methods of turpentining on a commercial scale is finished, but the results are indefinite. No further work is planned, but it would be desirable to do more if proper cooperation could be obtained.

200. Production of ethyl alcohol from wood (L-150).

Investigations under way for a number of years have resulted in various improvements in the process of making ethyl alcohol from wood, especially in the conditions of cooking and in the method of fermentation. The report covering the first portion of this work, both on species and on methods, has been written. Additional species have recently been studied. As war emergency work, cotton seed hulls and bagasse were studied and the laboratory work on these materials is practically finished.

The plans for further work include:

(*a*) Study of effect of catalyzers; (*b*) production of organic acids from wood sugars; (*c*) identification of the various wood sugars; (*d*) study of less costly fermentation procedures; (*e*) write up for publication the work on cotton seed hulls and bagasse. No further work planned on these materials.

201. Study of value of hydrolyzed sawdust as a stock food (L-A 150).

Work has been started in cooperation with the University of Wisconsin in which practical feeding tests are made.

Continuation along this line.

202. Ethyl alcohol from waste sulphite liquor (L-241).

One stage of work finished, report written and published in "Paper."

Cooperation with Section of Pulp and Paper on effect of: (*a*) sulphur acid; (*b*) different acid compositions, and (*c*) other catalyzers on sugar production.

203. An investigation of the chemical and physical properties of California eucalyptus oil (L-B 166).

Material obtained and work started.

Continue with special attempt to produce an oil which will conform with U. S. Pharmacopœia requirements.

204. The chemical composition of American woods (L-112).

A study of the chemical composition of American woods has been under way for a number of years. Seven or eight important species have been studied and a part of the results published as an article.

(*a*) Work on the comparison of species was stopped during the war but has been recently resumed. It will be continued according to the original working plan together with the necessary modification of methods which may develop from increased information on the subject.

(*b*) Work on the fusion of wood with alkali for the production of acetic acid is finished and the report published. This was emergency war work and nothing further along this line is planned.

205. Bleaching and equalizing color of heartwood and sapwood of various species (L-250).

Some work has been done on oak chair stock and a method has been developed on a small laboratory scale which gives satisfactory results.

Make commercial demonstrations in cooperation with some furniture factory and work on other species if possible.

206. The production and quality of American storax from Liquidambar styraciflua (sweet gum) (L-251).

Preliminary study and report finished. Cooperative study of production methods started.

Continue along this line with introduction of native products to consumers.

PATHOLOGY

207. Toxicity of preservatives with pure culture in petri dishes and jars (L-137).

Tests have been completed on various coal-tar creosotes and fractions, on water-gas-tar creosote, and mixtures of these with various fractions, spirittine, S. P. F. carbolineum, Morel preservative, B. M. mixture, zinc sulphate, cresol mixtures, beechwood tar distillates, preservol Mykantin, anthrasota, Barrett's grade 1 oil, and reports prepared. A number of articles published and also a Government bulletin.

Tests will be carried out on various preservatives referred during the year.

Assigned to Forest Products Laboratory, in cooperation with the Bureau of Plant Industry.

208. Relative resistance of untreated woods to decay (L-170).

These tests were initiated about ten years ago, and include several series of representative American woods. The tests fall under three subjects:

(*a*) By pure culture of fungi in jars (L-170*a*).

Regular inspections are continued as often as necessary.

Regular tests will be continued using different fungi and adding new woods as they become available.

(*b*) By fungous pit tests (L-170*b*).

Regular inspections are continued as often as necessary.

Tests will be conducted with new woods as they become available.

(*c*) The effect on the chemical composition of wood of the attack of fungi (L-170*c*). Preliminary work was completed and the report written. Continue the chemical study of the substances contained in wood which render it resistant or immune to fungi, in cooperation with the Section of Derived Products.

Assigned to Forest Products Laboratory, in cooperation with the Bureau of Plant Industry.

209. Determination of the minimum and maximum moisture content of wood which permits the growth of fungi (L-171).

Some preliminary work has been done and apparatus constructed.

Study to be completed as time permits.

Assigned to Forest Products Laboratory, in cooperation with the Bureau of Plant Industry.

210. Thermal and humidity death point study of a wood rotting fungus (L-212).

Some preliminary work conducted to determine in connection with project L-191 the temperatures and humidities that will kill various wood rotting fungi.

The relation of moisture to fungous growth will be further investigated on an extensive scale and temperature tests will be continued on various wood-destroying fungi to supplement earlier tests.

Assigned to Forest Products Laboratory in cooperation with the Bureau of Plant Industry.

INDUSTRIAL INVESTIGATIONS

211. Vehicle study (L-222).

(*a*) Data on methods and equipment for drying vehicle stock have been given to many of the vehicle manufacturers and resulted in an improvement in the results formerly obtained. Further work will be taken up as the occasion demands.

(*b*) The field work has been completed and preliminary work started to determine the thermal point of various wood-rotting fungi under dry and humid conditions in vehicle stock.

Toxicity tests will be continued, a few more steaming and drying experiments made, and report completed.

(*c*) Various methods of bending vehicle stock have been tried.

Bending work will be continued as time and funds permit.

212. A study of the use of wood in railway cars (L-237).

(*a*) Some cooperation has been carried on with the committee on the purchase of treatable timber of the American Wood Preservers' Association, although no work is now in progress.

No definite work planned. The work will be carried on whenever advisable.

(*b*) Several field trips have been made to various car factories in order to study their kiln drying problems.

No definite work planned. The work will be carried on whenever advisable.

(*c*) A study has been made to determine the advisability of using more wood in railway cars.

No definite work planned. The work will be carried on whenever advisable.

213. Shipbuilding (L-224).

(*a*) A handbook on the use of wood in shipbuilding has been prepared and sent out to various people for review and criticism before publication.

(*b*) Experimental deck has been caulked with various pitches and the necessary inspections made every week. The laboratory tests on the original pitches have been practically completed.

Continuation of inspections and interpretation of data are planned.

(*c*) The use of various species of woods for ships has been studied.

Work will be carried on as the occasion demands.

214. Wood waste exchange.

Lists of plants that have waste for sale and lists of plants that can use comparatively small pieces have been maintained for a number of years and have been the means of bringing together a great many buyers and sellers of wood waste.

The exchange will be maintained as in the past. Quarterly lists of buyers and sellers will be compiled.

Assigned to the Washington office of Forest Products.

215. Utilization of commercial woods by species. To bring together in convenient form the available information on the supply, demand, and properties of the different commercial woods and to show their relative values for various purposes. Results to be published in bulletin form.

The following reports have been issued: F. S. Bulletin No. 99, "Uses of the Pines," Dept. Bulletin No. 12, "Uses of the Beeches, Birches,

and Maples," Dept. Bulletin No. 523, "Utilization of Ash," Dept. Bulletin No. 683, "Utilization of Elm." A bulletin on the "Utilization of Black Walnut" is practically completed. Considerable work has been done on a report covering the utilization of the oaks.

During the year it is planned to complete the preparation of bulletins on walnut, the oaks, sycamore, and to get under way a bulletin on the hickories.

Assigned to the Washington office of Forest Products.

216. Lumber grading study (L-252).

(*a*) Considerable work was done before the war on the development of a universal grading rule applicable to all species and all regions. This work has been taken up again in cooperation with the National Lumber Manufacturers' Association after being discontinued during the war. Cooperation in developing a universal rule will also be arranged with consumers of various classes of lumber and with lumber dealers.

(*b*) A report is in preparation on the grading of lumber by manufacturers' associations.

Assigned to Forest Products Laboratory and Washington office of Forest Products.

217. Lumbering methods and costs (L-4, District 1–8). To secure data on methods and costs of logging and lumbering manufacture as a basis for stumpage appraisals. To secure data as a basis for the development of logging engineering. To conduct efficiency studies in logging and milling operations. Where possible these studies to be considered with reference to the practice of forestry.

Begun in 1912, and continued in all of the Districts until the beginning of the war. The following reports have been published: Dept. Bulletin 440, "Lumbering in the Sugar and Yellow Pine Region of California," Dept. Bulletin 711, "Logging in the Douglas Fir Region," Dept. Bulletin 718, "Small Sawmills and their Equipment, Construction, and Operation." "Report on Lumber Manufacture in the Douglas Fir Region," now ready for printing.

To be renewed during the year if personnel permits.

Assigned to all Districts.

218. Mill scale studies (L-1, District 1–8). To determine the mill overrun and the percentage of different grades of lumber obtained from various grades of logs of all important commercial species; to determine the relative quantity and quality of lumber manufactured from timber cut by National Forest methods and under methods prevailing on private lands; to show the effect of cutting regulations upon the yield of lumber and the amount and quality; to determine the practicability of using uniform log grades for particular species in timber reconnaissance, and also in timber appraisals.

Studies completed in District 1 for larch, western white pine, lodgepole pine, western red cedar, Engelmann spruce, western hemlock, and Douglas fir; in Districts 2 and 3 for western yellow pine; in District 5 for sugar pine, western yellow pine, Douglas fir, white fir, and incense cedar; in District 6 for Douglas fir and western yellow pine; in the East for tapped and untapped longleaf pine, maple, small yellow pine mills, red and white oak. In District 7 work has been done on northern hardwoods and on southern yellow pine in Arkansas. For a number of the above species several studies have been made to cover timber of

different quality and of different types of mills. A number of reports have been published in trade journals. Work was suspended during the war.

In District 6 an analysis will be made of the results of Douglas fir studies and possibly a further study undertaken during the year. A study of western hemlock will be made if a satisfactory mill can be found. At the Forest Products Laboratory the preparation of a general publication embodying the results of all the mill scale studies so far conducted will be begun. It is doubtful if other District studies can be initiated during the year.

Assigned to all Districts and Forest Products Laboratory.

219. **Lumber depreciation study (L-3, Districts 1-8).** To determine the depreciation of lumber in volume and quality from the time of sawing until that of shipment or sale, including depreciation in open-air seasoning, kiln drying, handling, storage, and machining, as a basis for more efficient operations and for National Forest appraisals.

Work under way several years. In District 1 studies conducted on western yellow pine, western white pine, and western larch. In District 5 on sugar pine, western yellow pine, Jeffrey pine, Douglas fir, white fir, and incense cedar. In District 6 on western yellow pine and Douglas fir. In the East on red oak, white oak, and southern yellow pine. For several of these species studies have been made covering different climatic conditions, etc. The work was suspended during the war.

In District 6 a further study of Douglas fir may be made if cooperation can be arranged. This may include also western hemlock. The results so far secured from all depreciation studies will be analyzed to determine whether sufficient data is available to justify a report covering all results for the entire country to date. It is doubtful if other field studies can be initiated in the Districts during the year.

Assigned to all Districts and Forest Products Laboratory.

GRAZING INVESTIGATIONS

ARTIFICIAL RESEEDING

220. **Artificial reseeding of depleted range lands.** Manti.

In 1910 areas were seeded at an elevation of 10,000 feet by officers of the Manti Forest. In 1912 two areas were seeded to Kentucky bluegrass, timothy, orchard grass, and Hungarian brome. The seed on one area was trampled in by sheep, and on the other area it was harrowed in. Thirty-two quadrats have been established to determine rapidity of establishments of vegetation, loss due to drought, and vegetative increment. In 1914 three additional areas, between 9,600 and 10,000 feet elevation were seeded to Kentucky bluegrass, timothy, and brome grass. In 1915 seasonal seeding tests were begun, plantings were made in spring, summer, and fall with Kentucky bluegrass and timothy. In 1917 six plots were seeded in strips to determine the practicability of revegetation by this method with the idea that seed from the seeded strips will be distributed and result in revegetation of adjoining areas. In 1918 a large plot was established on a long-used bedground, part of which was plowed and a part untreated and subsequently seeded to violet wheat-grass (*Agropyron violaceum*) and mountain brome-grass (*Bromus marginatus*). Observations to date indicate that the cultivated species are able to compete fairly successfully with native species

where the site is favorable to the growth of cultivated species. Kentucky blue-grass appears to be gaining ground after several years, although it was less promising than other species at first.

It is important to determine the longevity of various species worked with and to do this will necessitate continued observations for a number of years. One of the most important things to be worked out in the practical application of arificial reseeding is the proper selection of the lands. It is the plan to attempt to correlate lands suitable for artificial reseeding with the character of the native vegetation which they support. If this can be done the ill effects of such factors as excessive soil packing, for instance, which does not directly affect soil fertility, may be recognized. Date of completion, probably 1922.

Assigned to A. W. Sampson.

221. Testing the suitability of certain new varieties of alfalfa for range reseeding. Great Basin Experiment Station.

Approximately 100 plants of alfalfa, varieties Nos. 336 and 532, were planted in the nursery in 1913. In 1914 fifteen specimens of each variety were planted at an elevation of 9600 feet. The plantings at this elevation gave negative results. At the Experiment Station vegetative growth has been fairly good, but seed has not matured. Sites were selected and fenced for a plantation in the oak brush type in 1917 and the plantings were made in the spring of 1918. Owing to the dryness of the soil most of the plants died.

The plantings at the Experiment Station and at the higher elevations have shown that the alfalfas have no commercial value above 8000 feet elevation in this region as they do not produce seed at these elevations nor do they reproduce vegetatively. Plantings at these elevations, therefore, have been discontinued.

Some of the plants remaining in the oak brush planting site came through the season in fairly vigorous condition. Their growth and general development will be observed next season. Date of completion, probably 1920.

Assigned to A. W. Sampson.

222. Cultivation of indigenous forage plants for artificial reseeding. Great Basin and Fort Valley Experiment Stations.

Thirteen species of native forage plants have been tried out to date in the nursery at the Great Basin Experiment Station. Of this lot one species, *Agropyron riparium*, has proved well adapted to the climate and soil of the region, and has made remarkable growth and extension through vegetative reproduction. The other species have been either failure or of little promise. In 1913 similar experiments were started at the Fort Valley Experiment Station with thirteen native grasses. Of these, four show promising results, six have produced a thin stand, and three have been failures.

At the Great Basin Experiment Station the investigation will be continued with additional species, care being taken to select those which show possibilities in the way of extension of range. Seed of the species now in the nursery will be used for seeding under range conditions outside of the nursery. Also seed of *Mertensia*, collected on the Uinta Forest in 1917, will be used for experimental seeding on range near the Experiment Station. Further, an experiment is planned for the Uinta Forest in seeding depleted areas with seed of valuable native

forage plants collected on nearby range to test the feasibility of hastening the revegetation on denuded areas. At the Fort Valley Station observations will be continued until all species have produced seed. A report will then be written and the project will be closed or extended to range reseeding if the results warrant. Date of completion, indefinite at the Great Basin Experiment Station, probably 1919 at the Fort Valley Station.

Assigned to A. W. Sampson and G. A. Pearson.

223. **Artificial reseeding of range in Southwest.**

At the Jornada Range Reserve, two plots were seeded to slender grama and two to hairy grama in the spring of 1916. Two acres seeded to alfilaria in November, 1916. Additional seedings of alfilaria made in the winter of 1916 and 1917. All these seedings show negative results. During the spring of 1917 Russian thistle was seeded on part of the desert range. Thus far the results appear to be negative. The drought of 1917–18 was severe enough to kill out part of the native grama grass. Additional seeding tests were inadvisable during this period.

Climatic conditions are unfavorable to the success of introduced plants, but efforts will be continued to find some hardy species which will be successful and increase the forage crop. Such species as appear to have some promise will be tested. If possible hardy browse species will be selected later. Tests will be continued as species are available during the continuance of the investigations at the Jornada Reserve.

Assigned to C. L. Forsling.

224. **Improvement of forage crop on certain burned-over lands in western Montana and northern Idaho of District 1 and in District 6.**

Minor tests in seeding have been undertaken by local Forest officers, and favorable results appear to have been secured on the Okanogan Forest. The experiments have not been given the necessary attention, however, to justify conclusions. Seeding tests have been conducted beginning in 1917 in connection with the study of burned-over brush areas on the Crater National Forest, and the results are somewhat promising.

The experiments on the burned-over areas on the Crater National Forest will be continued and probably extended. The seeding done on the Okanogan Forest in the fall of 1917 will be continued under observation. A few additional tests will be started in District 6 and probably time will be devoted to examining areas where artificial reseeding may be warranted. Date of completion indefinite.

Assigned to D. C. Ingram.

NATURAL RESEEDING

225. **Range improvement by natural reseeding.** Great Basin Experiment Station.

Study initiated in 1912 on the "Two Mile Strip," Manti Forest. The quadrat and intensive plot methods of study employed to give records as to life history performances of the more important plant species. Observations made each season. Thirty-five quadrats and five protection plots 40 feet square established. One-half the quadrats chartered each year until 1917, when only a few of the important plots were chartered owing to lack of help. Complete root systems were obtained

for about 60 species in 1917, and approximately 150 photographs showing complete root systems and successional phenomena were made. An additional 40 sketches of root systems were made in the field, and a large number both of detailed and extensive sketches showing character of vegetation and succession were made under different field conditions. The object of the study of root systems is to develop a clear understanding of the succession of various important species, and the application of this succession in range management. This work was continued in 1918.

The results obtained in the case of the plant indicator studies appear to be fundamental in character to the management of the range. The data have been published in U. S. Department of Agriculture Bulletin 791. Close cooperation with the local officers of the Manti Forest was arranged last year and the investigative officers at the Experiment Station working with the administrative officers inspected most of the badly overgrazed range on the Manti Forest during the past season.

Owing to the excessive number of stock it was not possible to apply to any appreciable extent the deferred grazing. The Station officers will do all they can in 1919, however, to assist the Supervisor in applying improved range management methods generally. This extension of the project will result in a clear demonstration as to the value of the principles worked out by the Experiment Station and will eliminate difficulties hitherto encountered in controlling grazing on the portion of the Two Mile Strip which is under experimental observation.

Owing to soil erosion, heavy packing, and other "earmarks" of range depletion revegetation is taking place very slowly. It is essential that the study and observations be continued until we have more definite information as to the time required for revegetation under various conditions of depletion of vegetation and soil. Consequently this project will be continued for a number of years.

Assigned to A. W. Sampson.

226. Rotation grazing, Medicine Bow.

Initiated in 1914. Compartment No. 1 grazed season along by cattle, and No. 2 only after seed maturity in 1914 and 1915. This order reversed in 1916 and 1917 and again reversed and grazed as originally in 1918.

Fenced compartments will be continued to be grazed alternately, and observations as to results will be continued. Thus far the results show satisfactory progress. Date of completion, not earlier than 1920.

Assigned to L. H. Douglas.

227. Natural revegetation, Southwest.

A practical system of deferred grazing has been in application on 11 of 13 pastures at the Jornada Range Reserve during the past four years. A comparative study has been made of results secured on the Reserve and results secured on adjoining Public Domain range where grazing is unregulated. Up to 1917, 88 quadrats were located and chartered, some two and some three times a year in connection with this study. Some additional quadrats have been established during 1917 and 1918. To supplement the quadrats a number of small fenced areas have been established and quadrats established in and adjacent to them. The results secured up until 1917 were published in U. S. Department of Agriculture Bulletin 588. During 1918 a progress report was written

and the more important quadrats were chartered. The deterioration of the range, as a result of the continued drought, was carefully studied.

On the 50,000 acres under experimental management at the Santa Rita Range Reserve in Arizona, the number of stock grazing within the seven pastures was greatly reduced during the main growing season, July to October, and the range given a chance to reseed as a result of deferred grazing. This protection followed rather heavy grazing on most of the area for two years, and will give an excellent opportunity to observe improvement as a result of deferred grazing. Prior to 1918 80 quadrats and 15 small fenced areas had been established and charted several times to determine changes in vegetation. In addition several quadrats were established during 1918. Practically all the quadrats were chartered once and the more important twice. A progress report was written.

The quadrats already established will be recharted probably twice next year with few exceptions, and accurate record will be kept of the number and dates of animal days feed furnished in each pasture during the year. Careful observations for the areas as a whole will be made to supplement the detail data secured from the chartings. The studies will be extended and strengthened by the establisments of additional quadrats, small protected areas, and small pastures where definite control of the stock can be exercised. The recovery of the different types of vegetation from the detrimental effects of the drought will be carefully studied. Minor observations have already been started to determine more accurately the particular ways in which the forage plants reproduce at the two reserves. These indicate that reproduction vegetatively is perhaps more important than reproduction from seed. The drought has seriously interrupted these studies, but additional work will be undertaken along this line at the earliest opportunity as the method of reproduction may necessitate change in the proposed plans for grazing, which are at present based upon reproduction from seed rather than vegetative reproduction.

The great variation in vegetative growth due to variation in rainfall on these two reserves in different years, and the necessity for meeting the requirements of the stock have resulted in departures from any previously arranged intensity of grazing. These difficulties must be met in practical management and it is desirable, therefore, to meet them in the experimental management as they occur through a period of years. As a consequence this project will be continued as long as the reserves are under experimental management. Additional water development and additional fences will make it possible to intensify the study, and as time goes on the plan of grazing will be slightly varied between pastures of the same reserve in order to secure data on all possible phases of the problem.

Assigned to C. L. Forsling and R. R. Hill in cooperating with J. T. Jardine and W. R. Chapline.

228. Relation of frequency of grazing to vigor of vegetation. Great Basin Experiment Station.

Project initiated in 1916. Four plots each of native brome-grass (*Bromus marginatus*), Hungarian brome grass and violet wheat-grass (*Agropyron violaceum*), each plot containing 30 specimens, were planted in the nursery in the autumn of 1916. In 1917 and 1918 the herbage of these plots was cut according to the following plan:

Stage of growth when cut.	Native brome.	Hungarian brome.	Violet wheat-grass.	Time of cutting.
Cut after natural drying. Seed ripe and disseminated	Plot IV	Plot V	Plot XII	Oct. 8
Cut at maturity, leaving aftermath	Plot III	Plot VI	Plot XI	Aug. 27
Cut at maturity and aftermath removed	Plot II	Plot VII	Plot X	Aug. 27 Oct. 8
Cut four times during season	Plot I	Plot VIII	Plot IX	June 28 July 31 Aug. 27 Oct. 8

In each cutting, except where the plants had matured their seed and had dried up before harvesting, the green and dry weights were recorded. Complete root systems of five specimens, which were obtained from each plot at the end of the growing season, were prepared for chemical analyses with a view to determining the amount of starch and proteids stored in the tissues for the stimulation of next year's growth. The results to date have thrown much light on the proper season of grazing, longevity of plants according to frequency of grazing, and other phases pertinent to improved range management.

It is planned to establish more plots for detailed study of the character here reported, and it will be necessary to work with more specimens per plot. Accordingly seed of 11 species was collected and sown for transplanting next spring. About 100 specimens will be established in each detailed plot, the planting to be done in rows rather than in blocks. Larger plots no less than 125 of an acre will be established for the purpose of carrying out the same methods of herbage removal on a larger scale to check the results of the more careful work on the smaller plots as regards volume of herbage produced. The frequency and seasons of cutting will in all probability be continued as in the past. During each winter a chemical analysis will be made of the root and herbage samples obtained during the preceding summer. If initiated on the scale planned in 1919 the project should be completed by perhaps 1923.

Assigned to A. W. Sampson.

FORAGE PLANTS: DISTRIBUTION AND ECONOMIC IMPORTANCE ON NATIONAL FORESTS

229. Distribution, natural habits and economic importance of forage plants, Districts 1 to 8.

Nearly 38,000 specimens have been collected to date, representing about 4,800 species. During 1918 about 1700 specimens were submitted, identified, and notes in part furnished the collectors: 96 additional grasses have been reported since "Notes on Grasses" were printed; about 9500 plants have been mounted to date, properly labelled and filed in Washington, besides a great deal of similar work in District and Supervisors' offices; manuscript of economic notes for about 300 species were prepared during 1918; material for additional important genera were grouped and arranged for ready reference and a number of important genera check-identified in 1918; several new species were collected during the year, and extension of range established for a number of other species.

Will continue collections, paying special attention to observations

on economic value. Continue compilation of economic notes and submit booklets of notes on range plants of the National Forests for publication as soon as they can be prepared.

Assigned to W. A. Dayton.

PROTECTION

230. Effect of grazing upon reproduction of western yellow pine.

Main study and supplementary study started in 1912. The main study completed in 1915 and report published as U. S. Department of Agriculture Bulletin 580 in December, 1917. No field work on project during 1917 except the general observations. During 1918 all plots on the Coconino Forest were reexamined and the stakes reestablished in cooperation with the Fort Valley Experiment Station.

It is planned to reexamine the plots, perhaps every two years, for the purpose of finding out the percentage of the reproduction originally on the plots when the study was started, which eventually develops beyond injury by grazing, and to determine to what extent the new reproduction becomes established. It is possible that the study will need to be continued to find out if the desired amount of reproduction will come in eventually if grazing is continued and if so what delay has been occasioned by grazing and the effect of this delay upon the final mature stand of timber, either in quantity or time required to produce it. Date of completion, probably 1924.

Assigned to M. W. Talbot, and G. A. Pearson.

231. Effect of grazing on aspen reproduction, Great Basin Experiment Station.

The experiment was initiated in 1912. In all 122 sample plots 10′ × 50′ have been established. In addition four clear cut plots $^1/_{10}$ of an acre each, two of which are fenced and two unfenced, have been under observation since 1913. The results show that the rate of height growth of the plants and the intensity of grazing are the determining factors in the management of cut-over aspen lands. Sheep will have to be excluded from clear-cut aspen lands for at least two years following cutting. Moderate grazing may then be allowed without seriously interfering with the stand of aspen desired. Cattle cause very little damage to reproduction if moderate grazing is resorted to. U. S. Department of Agriculture Bulletin 741 presents the results of the investigation, and suggestions for the management of grazing in the aspen type.

The transects on the clear-cut aspen plots in Ephraim Canyon will be reviewed annually for three or four years. The plots established in standing timber adjacent to these clear-cut areas will also be examined. Observations on these plots will be continued until the reproduction is beyond damage by cattle browsing. The main project is completed. Supplementary work will be completed in 1920.

Assigned to A. W. Sampson.

232. Effect of grazing on erosion and streamflow. Great Basin Experiment Station.

Two comparable areas on typical local range at 10,000 feet elevation have been selected, fenced, mapped, and provided with sediment basins including drainage gates and shutters, water gauge registers, etc., for the measure of sediment and streamflow. Meteorological stations

established and observations made since 1913. Both erosion areas are grazed once annually by sheep. Records of all run-off and erosion secured in 1915, 1916, 1917 and 1918. U. S. Department of Agriculture Bulletin 675 entitled, "Range Preservation and Its Relation to Erosion Control on Western Grazing Lands," presenting the data and the conclusion of the study was published in June, 1918.

The experiment in general will be operated as in the past until a definite relationship can be established between the run-off and erosion on the two areas from a given storm. A special snow survey will be made on the areas in the spring of 1919. Date of completion, indefinite.

Assigned to A. W. Sampson.

233. **Planting to check erosion.** Great Basin Experiment Station.

Approximately 1300 cuttings of aspen, willows, mountain elder, wild gooseberry, currant, and two species of bunch-grass planted on two different sites during the seasons of 1913 and 1914. In 1916, 900 plants consisting of several species which had previously shown some promise were planted in contour terraces, and grass was seeded along the terraces in the fall of 1916. In 1917 approximately 350 specimens of wild gooseberry, sweet sage (*Artemisia*), and yellow brush (*Chrysothamnus*) were planted in June in contour terraces on a denuded and eroding southwest exposure at 10,000 feet elevation. Direct seeding of mountain elder and wild currant was attempted but with negative results. Seeding to cultivated and native grasses was carried out both on old terraces and on some of the new terraces. Mountain brome-grass (*Bromus marginatus seminudus*), mountain bunch-grass (*Festuca viridula*), porcupine-grass (*Stipa minor*), squirrel-tail grass (*Hordeum nodosum*), Nevada blue-grass (*Poa nevadensis*), and three native wheat-grasses were the species used. A number of additional contour terraces prepared in the fall of 1917 for planting in early spring of 1918. These new terraces are wider than the old terraces, as it was found the old ones were too narrow to hold the run-off.

Owing to the relatively heavy destruction of plants in the terraces through trampling by cattle and horses, measures were taken in 1918 to fence the planting site. The posts were set and the wire purchased and delivered for placement prior to the opening of the grazing season, 1919. No new terraces were made for the next spring planting as it is planned to replant terraces where the cover is not satisfactory. About 1500 plants will be set out in 1919. Date of completion, indefinite.

Assigned to A. W. Sampson.

234. **Effect of goat grazing upon range, timber cover, watershed, and development of improved methods of handling goats.**

Studies initiated on the Gila and Alamo Forests in 1915. Three goat ranges on the Gila and two on the Alamo under observation during the grazing seasons of 1915 and 1916. Twenty quadrats located and mapped; 105 tree reproduction plots established and examined; two bands of goats placed under a better herding system with several instead of one camp, and comparative study made of results under this system and under the old one-camp system; studies made to determine principal forage plants on goat ranges and species best suited to goat grazing; studies initiated to determine carrying capacity of goat ranges and adaptability of different classes of range to goat grazing; progress reports prepared in winter of 1916 and short article published. In

1917 and 1918 the studies on the Gila and Alamo were continued. In addition, during 1917, examinations were made and reports submitted covering prospective goat ranges on the Santa Fe, Carson, Crater, Siskiyou, Siuslaw, Klamath, Shasta, and Lassen National Forests. In 1918 prospective goat ranges on the Gila, Lincoln, and Coronado Forests were examined and reports submitted. Considerable interest was created among goat growers in possible future development of the goat industry on brush ranges at present unused. Papers were presented before the National Mohair Growers' Association, December 10-12, 1917, and December 5-7, 1918, and Arizona Goat Raisers' Association December 3-4, 1918. The results secured from 1915 to 1917, except the effect of goat grazing upon reproduction, were published in U. S. Department of Agriculture Bulletin 749.

If possible in two or three years the quadrats and reproduction plots on the Gila and Alamo Forests should be recharted and reexamined respectively. and allotments previously under observation should be examined to determine their condition and the effectiveness of the methods of management practiced. A report should be prepared on the effect of goat grazing upon reproduction. The information secured from the study should be disseminated among Forest officers with the idea of securing proper inspection and administration of goat ranges. The application of improved methods of management should be extended on Forests and public domain by furnishing information through associations, individuals, and by demonstrations. If possible demonstration experiments in the most approved management of goats on the range should be arranged with growers on Forest or public domain range in Arizona and New Mexico to show exact results of these methods on range and goats and their practical application. The proposed work as outlined is in the nature of a line of work rather than a project. Consequently the studies will continue until satisfactory methods of management are adopted generally on Forest ranges.

Assigned to W. R. Chapline.

235. Effect of removal of competing grasses by grazing, on the survival, height growth and increment of young coniferous trees. Halsey Experiment Station.

Working plan prepared, plots established, and first measurements made in 1916. Plots reexamined in 1917 and 1918.

It is planned to graze the experimental areas heavier than in the past if this proves practicable, and to continue observations. If heavier grazing is not found to be practicable, observations will be discontinued as the present intensity of grazing does not produce sufficient effect to warrant conclusions. The project may be closed or extended when the report of results is received in the next few months. Date of completion, probably 1922.

Assigned to Halsey Experiment Station and L. H. Douglas.

236. Effect of fire on forage, California.

Project initiated on California Forest in 1915. One area burned on a sheep allotment in the fall of 1915, and plots established to study plant succession and reproduction of brush following burning. Plots examined in 1915, 1916, 1917, and 1918. The observations show that a great deal of herbaceous vegetation came in the year following burning and has been decreasing in amount since. During the first year following

burning the brush reproduced rapidly and is gradually shading out the herbaceous vegetation. The first two years after burning the brush sprouts were fairly succulent and furnished a good deal of sheep feed. In the third year, however, the brush was becoming woody and very little of it was eaten by sheep. This fact and the gradual elimination of herbaceous species will probably result in the burned area being used but little if at all for grazing after the third year. Progress reports were submitted in 1917 and 1918.

In 1919 a grazing reconnaissance of 20,000 acres involved in this study will be made, the plots will be recharted in the spring and if necessary in the fall of 1919. Sufficient data will perhaps then be available to justify conclusions as to the advantage to grazing from burning brush areas similar to the one under study, the grazing carrying capacity of the burned area during each year for the three years following burning and the period during which the burned area is of value for grazing following burning. The sample plots will be continued for a number of years and will be reexamined probably each year to obtain additional data on vegetative growth as long as there is a change apparent. Date of completion, indefinite.

Assigned to F. D. Douthitt.

METHODS OF HANDLING STOCK

237. Small coyote-proof lambing enclosures in connection with lambing allotments.

Field work since 1910 on Cochetopa Forest. In 1914, 1915, and 1916 on Datil Forest. Report 1910 in Bulletin 97. Reports by local Forest officers 1911 to 1916. Three other articles published in National Wool Grower. The number of lambs saved has consistently been greater in the experimental band than in four to five check bands. Several sheepmen on the Cochetopa are installing similar improvements on their lambing ranges. Two large sheep producers on the Datil Forest have adopted the improved method, and improvements based upon the experiments have been adopted by many sheepmen.

In District 3 the project will be extended to include observations on lambing methods and results throughout the District for comparison with the results under the improved system. On the Cochetopa the experimental sheds and enclosures will be used by permittees who will report progress and success. General observations on lambing methods should be continued and reported with a statement of improvements along this line. U. S. Forest Service Bulletin 97 will be revised within a year or two, perhaps in 1919 if there is opportunity for field observations by the author during 1919. General observations should be continuous as this is an important line of work rather than a specific investigation, and there is much room for stimulating improved methods for Western States.

Assigned to J. T. Jardine.

238. Improved methods of handling sheep on Forest range.

Observations on Lewis and Clark, Madison, and Lassen Forests in 1912; study by Grazing Examiner on the Madison Forest in 1913 and 1914; study by a special man on Payette 1912, 1913, and 1914; study by Grazing Examiner on Bighorn in 1913 and 1914. Observations and good results on Madison, Helena, Lewis and Clark 1915–1917. On Ochoco, Wallowa, Whitman, Rainier, Malheur, Wenatchee, Umatilla, Cali-

fornia, Lassen, Fillmore, Fishlake, Manti, and Sevier Forests new method put into effect, one or two bands carefully studied. During 1917 aggressive effort made to secure adoption of the bedding-out system on all Forests, and remarkable progress was made. General observations continued to determine difficulties and ways of overcoming them. Four short articles published in National Wool Grower and a chapter in U. S. Department of Agriculture Bulletin 790 on Range Management. Results now being compiled with the expectation of preparing a manuscript for publication.

The bedding-out system of handling sheep has passed the experimental stage. Approximately 60 per cent of all sheep on the National Forests are now handled according to methods approaching this system as advocated by the Forest Service. Continuous effort will be made to secure the adoption of this method by the remaining 40 per cent of sheep owners, and to perfect a system of handling all sheep to more nearly approach the ideal desired. Additional demonstration tests under careful supervision may be necessary in 1919 but only as a part of the combination deferred and rotation grazing and improved handling of sheep demonstrations on the Medicine Bow and Gunnison Forests. Date of completion, continuous until satisfactory methods are adopted on all National Forests.

Forest officers administering grazing under the general direction of District and Washington offices.

239. Range management to avoid loss of stock due to starvation, disease, etc.

The Jornado Range Reserve of 200,000 acres, and the Santa Rita Range Reserve of 50,000 acres so divided as to reserve a portion of each area for use primarily during the dry period of spring and early summer. This plan makes it possible to reserve native forage to help tide the stock over the critical period of the year. At the Jornada Reserve 40,000 acres of grama grass range thus reserved has aided materially in reducing loss of cows from starvation during the past four years.

To supplement and further increase the reserved feed for breeding stock during critical periods, about one-third of the carrying capacity of the Jornada Reserve is used for grazing steers. During unfavorable seasons the number of steers can be reduced as necessary to provide additional range for the breeding stock. During 1917, for example, all of the steers were sold, thus providing one-third more range for the breeding stock. These steers are usually held on pastures which are suitable for grazing during the critical dry period in spring and early summer. This phase of management has materially aided in maintaining the breeding herd without loss and necessity of forced sales.

To supplement the range provided in the ways outlined above, native plants have been tried out both as hay and ensilage. Tobosa grass cut and fed as hay, and Tobosa grass tried as ensilage in 1916 proved of doubtful value. One hundred and fifty tons of soapweed was preserved in a pit silo, and a small amount fed in the spring of 1916. The results were promising. During the fall and winter of 1917 a special ensilage machine was designed and constructed, and was placed in operation on the Jornada Reserve in January, 1918, to cut the soapweed ready for feeding green. More than 1000 poor cows were fed soapweed and cottonseed products on the Jornada Reserve between January 1 and August 1,

1918. This feeding saved probably 500 head from starvation. This practice was taken up by other stockmen and it is estimated that over 100 herds were being fed soapweed by June 1, 1918. U. S. Department of Agriculture Bulletin 745, giving the results of this work, was published. The soapweed should be fed only during critical periods as the plants are slow growing. This will give the plants a chance to grow an additional crop after once being cut.

The native forage and soapweed for best results need to be supplemented by concentrated feeds. During the past three winters poor cows, bulls, and a great many calves have been fed cottonseed cake. This feeding is an important factor in reducing losses at the Reserve.

Prior to 1915 losses from blackleg at the Reserve were heavy. In 1915 a systematic campaign of vaccination was initiated, with the result that the loss has been materially decreased. In 1917, 800 doses of Germ Free Vaccine were used. This new vaccine gave excellent results and did away with the necessity for vaccinating three or four times before the animals are two years old.

The net result of the foregoing features of management to avoid loss has been that the losses from all causes at the Jornada Reserve were only 1.9 per cent in 1915, 1.5 per cent in 1916, 1.8 per cent during the bad year of 1917 and in 1918, 3.5 per cent. The best available figures for New Mexico as a whole show average losses of 10.6 per cent for calves, 5.6 per cent for yearlings, and 5.6 per cent for stock over two years of age. For 1917 the average was about 15 per cent and in 1918 from 15 to 50 per cent. This reduction in loss through better management is extremely important and stockmen are becoming interested in the improved management.

It is planned to continue with the investigations along the above lines. The amount of concentrated feed will probably be increased and the studies to perfect methods of using soapweed will be continued. Also the systematic vaccination of stock under 20 months of age will be continued, and it is probable that the new blackleg vaccine will be used in greater amount with a view to further reducing the losses from blackleg and at the same time reducing the cost of handling the stock in connection with vaccinating. Work along these various lines will be intensified as far as seems practicable under management on a large range unit. Similar tests which will be comparable to management conditions on a grazing homestead have been initiated with 40 head of breeding stock and will be continued. It is probable that a statement will be prepared for publication in 1919. Date of completion, continuous as long as the Reserves are under experimental management.

Assigned to C. L. Forsling and R. R. Hill.

240. Improving the grade of stock and increasing the calf crop by improved range management in southern New Mexico and southern Arizona.

At the Jornada Range Reserve 500 breeding cows were segregated from all other stock in the fall of 1915. In 1917 between 50 and 75 head of the poorest cows were culled out and replaced by selected heifers. An additional cull was made in 1918. This plan will be followed, gradually replacing the poor cows by selected heifers from the increase of the herd. The heifers will be held away from bulls until they are from twenty months to two years of age. Purebred Hereford bulls were

purchased for this herd in 1915. Additional purebred bulls have been purchased each year since, the best ones being retained for this herd and the others used in the main herd.

The main herd is approximately 1500 breeding cows. From this herd about 1000 poor grade, off-colored, and old cows have been culled out and sold. An equal number of selected heifers have been placed in the herd. Purebred bulls have been used exclusively during the past three years. The average grade of the breeding cows has been greatly improved and about 90 per cent of the calves are now straight white face of good form. Yearling steers sold from the Reserve in 1917 brought from $2.50 to $5 more per head than steers of the same age from the herd on the outside range.

In 1916 the calf crop in the 500 head herd was 81 per cent; in 1917, 68.2 per cent; in 1918, 80 per cent, making an average of approximately 76 per cent for the three years. The calf crop for the main herd in 1916 was 69.2 per cent; in 1917, 63.2 per cent; in 1918, 55.4 per cent, an average of approximately 63 per cent for the three years. This shows a big advantage in favor of the smaller herd with better care. The average calf crop for southern New Mexico in 1916 was not over 60 per cent, in 1917 it is estimated at 25 to 40 per cent, and in 1918 from 20 to 40 per cent.

At the Santa Rita Reserve similar investigations were begun in 1916. Drought and lack of facilities for handling the stock year-long have interfered with the investigations. However, sufficient data have been secured to show possibilities similar to those shown at the Jornada Reserve in the increasing of the calf crop and improving the grade of stock. In two of the herds, the poor grade bulls used prior to 1916 have been replaced by registered Herefords; the breeding cows are being improved in grade by selling off poor grade and off-colors as rapidly as better grade heifers are available to replace them.

The calf crop has averaged approximately 70 per cent for three years. For one herd of 100 to 250 cows the calf crop in 1916 was 85.7 per cent; in 1917, 81.8 per cent, and in 1918, 83.1 per cent. The average calf crop for Arizona was given as 57 per cent by reports from stockmen in 1914.

The improvement in grade and increase in calf crop has been facilitated greatly by the increased feeding and reservation of native forage as outlined under the project. Range Management to avoid losses of stock; keeping the cows in thrifty condition and taking good care of the bulls being important factors in securing a large calf crop. The increased water development, segregation of breeding stock from dry stock, and general care of the herds have aided in securing the increased calf crop. The investigation under way will be continued.

At the Jornada Reserve an additional test in management with 40 cows was started in 1917. This test was interfered with by the severe drought in 1918 but will be continued as soon as conditions warrant. The favorable results from the 500 head herd have convinced our cooperator, Mr. C. T. Turney, that it will pay him to initiate similar management with the main herd of 1500 head. As soon as the drought is broken, therefore, the cows in the main herd will be carefully selected and will be given better care than in the past. If these three tests can be carried out as planned we will secure records for range herds of 40 head, 500 head, 1000 to 1500 head.

At the Santa Rita Range Reserve difficulty is still anticipated in securing adequate control of the stock and breeding operations, owing to the difficulty of an assured year-long water supply adequate to warrant proper division of the range to accomplish the most desirable plans of management, and to the fact that there are four cooperators. There has, however, been a marked improvement in the stock since 1915 and it is believed that improvement will be still more rapid in the next few years regardless of the difficulties. Date of completion: Continuous during the periods that the Jornada and Santa Rita Range Reserves are under experimental management.

Assigned to J. T. Jardine, C. L. Forsling and R. R. Hill.

241. Cost of handling stock under pasture and improved methods of management as compared with the cost on open range.

A record of the cost of operating the Jornada Range Reserve has been kept for four years, and attempt has been made to secure data on the cost of handling similar outfits under open range conditions. It is difficult to secure figures for the outside range, however. The costs have not been analyzed to date, and probably will not be for a year or two unless special need arises for specific figures along this line. Similar records are being collected on the Santa Rita Reserve.

Careful records will be kept as to the cost of management of the Reserves as a whole, and cost of different phases of management. Similar data will be collected as far as practicable for outside range conditions. Date of completion, continuous during the period of the Jornada and Santa Rita Range Reserves are under experimental management.

Assigned to C. L. Forsling and R. R. Hill.

242. Handling stock on browse range.

To determine primarily (1) whether stock, particularly cattle and sheep, can economically utilize range where the cover consists practically of a pure stand of browse composed of one or several palatable species, (2) what basis should be used in estimating the carrying capacity of such lands for the different classes of stock, and (3) what effect the class of stock grazed may have on the permanency of the broader browse types. It has been suggested that where browse constitutes 75 per cent or more of the forage the vegetation other than browse, regardless of species, may be disregarded in deciding the intensity of grazing for the type. On the other hand some argue that this practice would result in a destruction of the herbaceous cover and hence render the range of no value for the grazing of cattle. The whole problem requires careful investigation.

It is the plan to experiment with both cattle and sheep. Since it will be necessary to have complete control of the stock they will be handled in pastures. During 1919 the problem will be looked into on the Dixie Forest, and the locations for the pastures selected. A general survey of the browse utilization on the Tonto Forest will be made and areas selected for detailed investigation. Date of completion, a single season would afford results of much immediate practical value. Three seasons would probably suffice in which to complete the project.

Assigned to A. W. Sampson and M. W. Talbot. Will be extended to District 5 later.

CARRYING CAPACITY

243. Carrying capacity, all Districts.

Range for four bands of sheep under observation, Deerlodge Forest 1912–13; 3 bands 1914; 2 bands 1915–16; 8 bands 1912–13, 6 bands 1914, and 4 bands in 1915 on Madison Forest. Range for 250 cattle under observation 1914–16 on Lewis and Clark Forest. In 1918 a Grazing Assistant was assigned to the cattle carrying capacity study on the Lewis and Clark Forest and report prepared. In this test, as in many of the other observations which have been taken, difficulty has been encountered in securing adequate control of the stock.

Observations on a number of pastures in District 3 in 1914 and 1915, but no conclusive results secured. Observations on three bands of sheep on Targhee in 1913 and 1914; 1 band on Manti 1913; 3 bands in 1914, and 2 bands in 1915–16; 2 bands on Caribou in 1913 and 1914, 3 bands in 1915, 5 in 1916; 2 bands on Fillmore in 1916. During 1917 and 1918 a great deal of data have been accumulated by some 20 odd men assigned to special range inspection or extensive reconnaissance. Carrying capacity has been estimated by allotments and units, and these estimates will be used as a check in actual grazing management. Revision in the figures will be made as improvement in management becomes effective. Several additional pastures have been placed under observation. Short article published in National Sheep Breeder and a chapter included in U. S. Department of Agriculture Bulletin 790 on Range Management.

The collection of data by Grazing Examiners on special range inspection will be continued. The carrying capacity study on the Lewis and Clark will be discontinued as an intensive study. Data secured from observation by local officers and permittees will be reported. It was planned during the winter of 1918–19 to have the Grazing Examiners in each District bring together all the results on carrying capacity from the special studies and from intensive and extensive reconnaissance, the idea being to prepare a preliminary table of carrying capacity figures for each District and for Forests by groups. This plan was interfered with by a number of men leaving for military service. It is hoped that this part of the project can be undertaken in 1919. Following such a compilation a more definite program for carrying capacity studies will be developed for adoption as funds and men are available. Carrying capacity will be a problem of importance for many years, and, therefore must be continuous. Specific studies may be completed and others initiated, but the main study of carrying capacity will go on as it is a line of work rather than a specific study in a given locality.

Assigned to Grazing Examiners under the general direction of J. T. Jardine.

244. Utilization of bunchgrass ranges, District 3.

Observations made on three pastures on the Apache Forest in 1914 and 1915. General observations on the Coconino and other Forests. A drift fence on the Apache designed to hold stock on the bunch-grass range in question nearly completed in 1917, and valuable data as to the value of bunch-grass range for cattle has been secured.

The bunch-grass range placed under use for cattle grazing by the construction of the Apache drift fence will be inspected from time to

time, and observations will be made on other Forests in the District. Construction of range improvements and improvement in control of stock are essential to successful study of this problem, and the progress made will depend upon the rapidity with which the necessary improvements and control of stock are secured. The study will be continued until satisfactory utilization of the bunchgrass ranges is secured, or until satisfactory utilization is dependent upon range improvements entirely rather than as at present upon lack of information as to the value of such range and satisfactory methods of utilization.

Assigned to M. W. Talbot

245. Carrying capacity of range in southern New Mexico and southern Arizona.

Records of the time of grazing and animal days feed furnished by each of 13 pastures on the Jornada Range Reserve have been kept for five years. The greater part of the area has been classified into range types, so as to determine carrying capacity as a whole for the Reserve and carrying capacity by large range types. Data for three years were published in U. S. Department of Agriculture Bulletin No. 588. Similar work is being done at the Santa Rita Range Reserve, and records are available for 9 years on two small pastures and for two years on the entire 50,000 acres.

On the Jornada Range Reserve especially the comparative carrying capacity of range under fenced control and proper management, and range not under fence is being studied. The drought of 1917–18 has greatly influenced results. A year of recovery will be necessary before the real significance of drought as a factor in carrying capacity over a period of years can be decided.

The investigations as outlined above will be continued and will be itensified as rapidly as facilities for a more specific study of carrying capacity by range types are provided. The observations will be extended to cover more range throughout southern New Mexico and southern Arizona as rapidly as possible. The results of these studies will be combined with carrying capacity data from District 3 eventually. Date of completion, continues as long as the Reserves are under experimental management.

Assigned to J. T. Jardine, C. L. Forsling and R. R. Hill.

METHODS OF DEVELOPING STOCK WATERING PLACES

246. Number, distribution, and cost of watering places on cattle ranges of the Southwest.

During the past four years careful studies have been made at the Jornada Range Reserve to determine the distance that permanent watering places can be apart and still secure reasonably efficient utilization of the range. This distance has tentatively been decided as 5 miles. To supplement such existing permanent watering places, numerous small tanks have been constructed on the Jornada Reserve, and it is found that where conditions are favorable to the construction of such tanks and accumulation of water in them to be used during a portion of the year, the money spent for such water development is a good investment. This supplemental water results in better distribution of the stock, more equal utilization of the range more succulent feed, less waste of energy in travel by stock, and the possible protection of

range around permanent waters for use during critical periods when the temporary watering places go dry.

In District 3 observations of water distribution and methods of developing water on the National Forest ranges have been made over a period of years with a view to eventually formulating effective methods of water development and effective distribution of watering places to secure maximum utilization of the range consistent with the difficulty and cost of water development.

The investigations at the Jornada Reserve will be continued to determine the difference in carrying capacity of range where the distance between watering places is variable. Methods of developing water and costs, especially of tank construction, will be further observed. The observations on National Forest ranges will be continued. Similar observations to those at the Jornada are being conducted at the Santa Rita Range Reserve and will be continued.

Assigned to C. L. Forsling, R. R. Hill and M. W. Talbot.

POISONOUS PLANTS

247. Eradication of poisonous and unpalatable plants from the range, all Districts.

At the Great Basin Experiment Station studies have been under way to determine the practicability of eradicating larkspur by cutting above ground and by grubbing since 1913. On an experimental basis the Experiment Station has concluded that cutting above ground four times during a period of three years is the cheapest way of eradicating larkspur on areas relatively free from rock, brush, or timber. The Station, however, advocates the test of this method on a practical basis to secure a comparison of costs with effectiveness of grubbing before the cutting method is finally advocated for use under practical range conditions.

As early as 1913 minor tests in the eradication of larkspur by grubbing were initiated on the Forests in California In 1913–14–15 and 1916 eradication by this method was tested out and greatly enlarged until in 1915 a practical test by grubbing out 68 acres of larkspur from a range unit of about 14,000 acres was undertaken on the Stanislaus Forest. The eradication was approximately 95 per cent effective, and the losses of live stock were reduced below the average losses in previous years sufficient to more than cover the cost of eradication. During 1915, 1916, and 1917 similar work was done on a great many Forests in Districts 2, 4, and 5. A total of about 1,900 acres of larkspur was eradicated during this period. In 1918 the eradication planned was interfered with by difficulty of securing labor. In spite of this fact, however, several hundred acres of larkspur were grubbed. With few exceptions the value of the stock saved as a result of the eradication work has been sufficient in one year to cover from one-third to two times the cost of eradication. The methods developed and the results secured are so satisfactory that stockmen generally are willing to contribute 50 per cent of the cost of eradicating the plants and in some cases are undertaking the eradication of their own accord. Farmers' Bulletin 826 presents the methods of eradication and results secured.

It is planned to continue larkspur eradication as a range improvement project in cooperation with stockmen as fast as funds are available. The work will be done under the direction of trained men as far as

practicable, and special examination will be made in advance of eradication so as to make the actual work of grubbing out the plants as effective as possible, and avoid undertaking eradication on areas where the probable saving in live stock as a result of eradication will not be sufficient to justify the cost of the grubbing. As soon as it is feasible to do so, a practical demonstration of eradicating larkspur by cutting, in accordance with plans developed by the Great Basin Experiment Station, will be undertaken.

Observations have been made in District 3 to determine the possibility of eradicating loco by grubbing, and the possibility of reducing losses from loco poisoning by a change in the method of range management and the time of grazing. A small amount of study has been devoted to the problem of eradicating death camas and sneezeweed. Observations along these lines will be continued, and if the general conclusions appear to warrant it further investigations will be initiated as soon as funds and men are available. It is probable that the problem of successful management of areas of range infested with loco will be given a good deal of attention during 1919. Date of completion; the work of eradicating larkspur will undoubtedly be continued until the practical possibilities of eliminating losses of live stock in this way have been exhausted. Investigations as to methods, costs, etc., will probably be discontinued within the next two years, during which time it is believed that methods will be sufficiently standardized to obviate the necessity for further special study. Work on eradication of other poisonous plants will probably continue indefinitely.

Assigned to A. W. Sampson, and Grazing Examiners.

TYPES

248. Climatic characteristics of vegetative belts on the Manti Forest.

Climatic records of air temperatures, precipitation, sunshine, and wind velocity have been made during the past four years at three stations. One station is located in the oak brush type, one in the aspen-fir, and one in the spruce type. During 1917 plants were grown at the three stations to ascertain the relation between certain climatic factors and the plant growth. The results are reported in U. S. Department of Agriculture Bulletin 700, "Climate and Plant Growth in Certain Vegetative Associations."

During 1919 the observations at the three stations will be continued if available help will permit. Date of completion, indefinite.

Assigned to A. W. Sampson.

EXHIBITS

249. Exhibits, illustrative features for educational purposes (cooperation with grazing studies), Great Basin Expt. Station.

The value of exhibits, especially the more permanent illustrations is well known. Grazing, so far as concerns numerous well tested methods of improved range management, is not well represented in way of exhibits yet many of the more important principles can be readily illustrated. There is, of course, nothing new or original about this work; it merely affords an additional means of publishing results.

The more permanent type of illustrations, such as those made from wood pulp, for instance, are most valuable. Pictures, graphs, and lantern slides are also proposed, however. The Office of Education will

cooperate with the Branch of Grazing in the preparation of exhibits. Grazing will furnish the material (photographs, graphs, sketches, etc.), while the Office of Education will be responsible for the final preparation of the exhibit. Date of completion, continuous. It should be the aim to prepare exhibits as important new principles are developed.

Assigned to J. T. Jardine, A. W. Sampson, and Grazing Examiners.

ECONOMIC INVESTIGATIONS

250. **Study of pine lands of the South Atlantic and Gulf States (project E-2, D-8; combination of former projects M-10, D-8 and Z-9, D-8).** Possibilities of the South for continuing lumber and turpentine production, and as an outlet for the growing demand for agricultural and grazing land: (*a*) segregation of agricultural and forest lands; (*b*) fire protection; (*c*) advice to owners on management of forest lands.

Extension of the study begun in 1914 by E. S. Bryant in the Alleghany mining belt. The southern pine region is considered the most important field for this study on account of the large amounts of cut-over lands and the need for their development along sound economic lines to prevent their becoming non-productive.

Assigned to Austin Cary and W. R. Mattoon.

251. **Possibilities of logged-off land for forestry (project E-3, D-8; formerly Z-10, D-8, special studies).**

Begun 1916. Completed 1918, after Mr. MacKaye's transfer to the Department of Labor, and results published in Dept. of Labor Bulletin "Employment and Natural Resources," 1919.

Assigned to Benton MacKaye.

Completed.

252. **Study of privately owned cut-over lands in the Pacific Northwest (project E-4, D-1, 4, 5, 6, 8; formerly Z-11, D-1, 4, 5, 6, 8, special studies).** To determine the character, extent, economic significance, and possible use of cut-over lands under private ownership in the Pacific Northwest, whether denuded or covered with second growth, with special reference to their value for the practice of forestry.

Begun as a project, in 1917, although considerable information previously gathered in the lumber industry study was utilized.

Field work completed and report prepared. Report will perhaps be issued as a joint publication by the Departments of Labor and Agriculture (Forest Service).

Assigned to S. T. Dana, in cooperation with the Districts concerned.

253. **Study of Government control of privately owned timberlands in Europe (project E-5, D-8; formerly Z-12, D-8, special studies).**

Begun in 1917. Publication: "Public Control of Private Forests in Norway," by S. T. Dana, Jour. Forestry, May, 1919, Vol. 17, No. 5: 497–502.

Study of all available literature on the subject as a basis for a final report.

Assigned to R. Zon and S. T. Dana.

254. **Economic study of the lumber industry (project E-6, D-8; extended to include former project L-6, D-8).** To ascertain the fundamental conditions controlling the ownership of stumpage and the production and marketing of lumber with special reference to their bearing upon

conservation and timber supply, upon stable conditions in the industry, and upon forestry; and also to present a historic and economic analysis of the public timber resources of the United States with special reference to the development of a definite timber sale policy; to state the present policy and indicate the opportunities for the purchase of timber from the National Forests; to keep in touch with current economic developments in the lumber industry with particular reference to their bearing upon forestry.

Begun 1914. Stumpage and manufacturing conditions were studied in the Pacific Northwest, California, the Inland Empire, and the South. Distribution was studied in the Middle West. The following reports have been published: "Some Public and Economic Aspects of the Lumber Industry," by W. B. Greeley; "Distribution of Softwood Lumber in the Middle West, Wholesale Distribution, Retail Distribution," by O. M. Butler; "Substitution of Other Materials for Wood," by Rolf Thelen. (Reports 114, 115, 116 and 117, U. S. Dept. of Agr.). Other publications were planned to cover the technical and forestry phases of the question. Regional stumpage and manufacturing reports have been practically completed. Some of the technical reports may be printed during the year.

Reports under way to be completed as soon as possible; continuation of the study to keep in general touch with developments in the lumber industry, this to be expanded as soon as facilities permit to cover special phases. Reports in preparation and assignments:

Forestry and the Lumber Industry, assigned to H. S. Graves.

Timber Ownership and Lumber Production in the Southern Pine Region, assigned to C. S. Smith and R. C. Bryant.

In the Douglas Fir Region, assigned to Austin Cary.

In the Inland Empire, assigned to D. T. Mason.

In California, assigned to C. S. Smith.

Public Timber and Its Uses, assigned to W. B. Greeley.

Utilization of Low-grade Lumber and Mill Waste, assigned to H. F. Weiss.

Adaptation of Lumber Manufacture in Grading to the Requirements of Consumers, assigned to H. S. Betts.

255. Economic study of thé pulp and paper industry.
To ascertain the fundamental conditions controlling the ownership of stumpage and the production and marketing of pulp and paper with special reference to their bearing upon conservation and timber supply and upon forestry; to keep in touch with current economic developments in the pulp and paper industry with particular reference to their bearing upon forestry.

Begun in 1918. A few short articles published.

Continue in accordance with the general plan.

Assigned to Austin F. Hawes.

256. Market studies (project E-7, D-1, 2, 3, 4, 5, 6, 7, 8; formerly L-5).
To ascertain: (1) consumption of forest products and location and nature of demands in regions adjoining the National Forests; (2) trade and transportation conditions which now govern source of timber supplying

this demand; (3) in localities where National Forest timber is not utilized, the causes which prevent such utilization; and to outline measures for extending local use; (4) to serve as a basis in part for plans of management on the National Forests.

Much information obtained in all Districts before the war. Reports published for Oregon and Washington showing production and consumption of forest products in these States. Districts 1 and 3, in cooperation with the Forest Products Laboratory, conducted investigations to determine possibilities of wider use of local timbers for mining, causes of breakage of western yellow pine for ties, and value of white fir for ties.

Work will, if possible, be taken up during the year in all the National Forest Districts. Upon completion of District studies a general report will be prepared outlining the services of the National Forests in supplying local markets.

Assigned to all Districts and Forest Products Laboratory.

257. **Forest products statistics** (**project E-8, D-8**). To collect (1) annual statistics on production of lumber, lath, and shingles, pulpwood consumption and wood pulp production, tie and pole consumption and preservative treatment, and fuel wood production; (2) periodic statistics of production or consumption of other forest products such as cooperage, veneer, etc.; (3) stumpage and lumber prices as an indication of market trend and as a basis for National Forest appraisals.

Lumber production statistics collected and reports published annually since 1905 except in decennial census years when the work was done by the Bureau of the Census pulpwood and wood pulp statistics since 1916; tie and pole preservative statistics since 1915; wood fuel statistics since 1916 in cooperation with the Bureau of Statistics; cooperage statistics collected in 1918; lumber price statistics since 1909; stumpage prices since 1913. Except on prices the collection of statistics for 1919 will be in cooperation with the Bureau of the Census.

Collection of statistics by the Forest Service will be resumed in 1920. During the current year a general summary will be prepared incorporating up to the present time all available statistics on production or consumption as well as those on destruction of timber resources, as an indication of the trend of the depletion of timber resources.

Assigned to F. H. Smith, A. H. Pierson, R. K. Helphenstine, Jr., in cooperation with District offices.

258. **Forests and forest products in the war** (**project E-9, D-8**). To show the value of forests and forest products in connection with the various phases of warfare, the extent of their use, and the bearing upon forestry.

Collection of data begun in 1919.

It is hoped to complete and publish a report during the current year.

Assigned to E. H. Clapp.

259. **Woodlot economic survey** (**project E-10, D-8**). To secure first-hand data to show the value of farm woodlands and their place in the scheme of farm management in different representative sections of the eastern United States; specifically, to determine the importance of

farm timber in supplying the farm with wood products, its possibility of supplying work in slack seasons, its cost as a farm enterprise, and the value of the woodlot products obtained. See also related project M-5, D-8 (woodlot management studies).

Begun in 1915. From 1915 to 1917 more than 1000 farms were canvassed in the following counties:

Massachusetts,	Windham Co.	Iowa,	Jones Co.
Vermont,	Franklin Co.	Nebraska,	Gage Co.
Pennsylvania,	Chester Co.	North Carolina,	Randolph Co.
Indiana,	Madison Co.	South Carolina,	Marlboro Co.
Indiana,	Jackson Co.	Tennessee,	Rutherford Co.
Indiana,	Kosciusko Co.	Alabama,	Morgan Co.
Wisconsin,	Marathon Co.	Louisiana,	Ouachita Co.
Minnesota,	McCloud Co.	Missouri,	Barry Co.

The resulting data were compiled, reviewed by the Office of Farm Management, and are now put in shape for the final report. In 1919 additional data were secured, in accordance with the general plan, on about 100 farms in Geauga County, Ohio, and Butler County, Pennsylvania. These data have not yet been tabulated.

The original plan confined the study largely to the more highly developed and prosperous agricultural regions with the most fertile soil, in which the investigations would not reflect the service of the woodlands to the best advantage. It is, therefore, desirable to cover also the regions where farming is less developed, either because of less fertile soil, more rugged topography, lack of drainage, or other factors; and it is proposed to extend the study to the following regions, in order of importance: (1) Pennsylvania and New England (except possibly Maine). (2) The Piedmont area of North Carolina and also additional areas in northern Alabama, nothern Louisiana, the Ozark region of Missouri, and in northern Wisconsin. (3) New York, southern Ohio, Appalachian parts of Tennessee, southwestern Virginia, West Virginia, and northern Georgia.

Assigned to E. R. Hodson, for the Forest Service, in cooperation with the Office of Farm Management.

260. Pulp and paper possibilities of the National Forests (project L-193).
Surveys have been made and considerable data have been gathered to show the economic aspects of the development of pulp and paper plants to utilize woods from the National Forests.

Continue arranging and analyzing data as time permits.

Assigned to Forest Products Laboratory.

261. Wood-using industries of New York States (project U-59).
A former report on the wood-using industry of New York State is considerably out of date. The study is being made in cooperation with Syracuse University.

A new study of State industries is under way. The former report will be revised and additional emphasis will be laid on the relation between the industries and the forests of the State.

Assigned to Washington Office of Forest Products.

BUREAU OF PLANT INDUSTRY

WILLIAM A. TAYLOR, Chief

INVESTIGATIONS IN FOREST PATHOLOGY

Haven Metcalf in charge

262. **Pathological problems in wood conservation, in cooperation with the Forest Products Laboratory.** To work out miscellaneous problems on the pathological aspects of wood conservation. Studies are made of the specific toxicity of wood preservatives against certain timber-rotting fungi; of the causes, conditions, and means of control of decay in building timbers under yard and storage conditions, and in mining timbers; of the histology and cytology of wood rots in general; of the natural resistance of various species of wood to decay; and of the relation of moisture, temperature, and other surrounding conditions to decay.

Status.—The work was begun in 1909 and is carried on at the Forest Products Laboratory at Madison, Wisconsin.

Results.—Definite knowledge has been obtained of the causes of certain types of decay of mining timbers, of the causes and conditions of various wood rots, and of the specific action of various preservatives. A method has been developed for quickly testing the toxicity of preservatives against pure cultures of wood-destroying fungi (method and tests published in Department Bulletin 227). About 6000 such tests have been completed. A method of testing the toxicity of heavy oils has been invented. Studies of conditions surrounding structural timber in storage show that decay in storage is preventable by slight and perfectly practicable changes in lumber-yard management, as set forth in Department Bulletin 510. Full data have been secured on the temperature range of 73 species of wood-destroying fungi. Practical results are reflected in work of the Forest Products Laboratory.

To be continued along the same lines.

Assigned to C. J. Humphrey and Paul V. Siggers.

263. **Diseases of forest nursery stock.** Investigation of these diseases with reference to control. This project involves the testing of the effects of various soil fungicides and amendments, of spraying, and of modification of nursery practice on "damping-off" and other nursery diseases; also greenhouse and laboratory experiments on the life history of the parasites which cause "damping-off" and the factors affecting them, with a view to the development of new control methods.

Status.—Begun in 1910. The work is done in cooperation with the Forest Service and private nurserymen. Field tests at Cass Lake, Minn., and Halsey and Nenzil, Nebr., laboratory and greenhouse work at Washington, D. C.

Results.—"Blight" of coniferous seedlings has been controlled by change in methods of watering. "Damping-off" on most soils, both in the East and West, has been controlled by treatment with sulphuric acid; amounts needed for a number of different localities have been determined. Treatment with copper sulphate has been developed in alkaline soils on which acid is not satisfactory. The weed destruction alone pays the cost of treatment at many nurseries. Part of the results are given in Department Bulletin 453. A disease similar to "damping-

off," but caused instead by excessive soil heat, has been studied, and the distinctive symptoms and preventive measures have been described in the Journal of Agricultural Research, Vol. 14, No. 13. The cause of the destructive nursery blight on cedars has been discovered, and the experimental work with it is described in the Journal of Agricultural Research, Vol. 10, No. 10. Evidence has been obtained indicating the value of spraying in controlling this disease. At least seven distinct fungi are able to cause "damping-off" of conifers. The identity of certain of the parasites with those causing diseases of crop plants has been demonstrated.

To be discontinued after publication, on account of lack of available investigators.

Assigned to Carl Hartley (resigned) and Annie E. Rathbun.

264. Cooperative field studies and demonstrations in forest pathology. To determine the best methods of controlling forest-tree diseases, particularly in the National Forests. From detailed and statistical studies of diseased stands in typical areas, rotation and cutting cycles based on diseases are established, improved marking and scaling methods developed, and exact percentages determined.

Status.—Begun in 1910. Work is in cooperation with the Forest Service, at Spokane, Washington, Albuquerque, New Mexico, San Francisco, California, and generally throughout National Forest Districts 1, 3, and 5, and a few localities in District 6.

Results.—The "sanitation clause" (Standard Clause No. 57, p. 308, National Forest Manual, Regulations and Instructions), which requires the purchaser in Government timber sales to cut all snags and all defective trees marked and to remove and pay for all merchantable lumber contained in such trees, has been developed by the work under this project. These studies also guide planting plans for the future forest in these particular localities, establish a definite cull percentage in place of an empirical one, and establish definite belts in which empirically found cull percentages may be more accurately applied. Studies of the pathology of the so-called inferior species show in the species so far studied that the inferiority is due to disease susceptibility. The age at which decay reaches practical importance (age of decline, critical age) is determined, which becomes a limiting factor in rotation (Department Bulletin 275). The studies on incense cedar along this line are practically completed. In this species definite external symptoms of rot have been defined which enable the marker and scaler to determine the internal condition of tree and log without cutting, thus saving substantial expense. The discovery of a brush-rotting fungus (Poria sp.) and studies of its activities have led to the substitution of "pulling" brush for piling it in localities in Arizona, New Mexico, and Arkansas, where it is difficult to pile and burn it on account of the shortness of the season during which burning is safe. (This project includes those listed under Forest Service, Protection, Diseases, under the direction of Doctors Meinecke, Weir, and Long.)

More extensive work in this line is planned for District 6.

Assigned to E. P. Meinecke, James R. Weir, W. H. Long and J. S. Boyce.

265. Miscellaneous forest-tree diseases. Investigation, with reference to control, of the nature and life history of various tree diseases and

of the effects of smelter fumes, smoke, and gasses upon trees. The usual methods of investigation of plant diseases are applied to forest-tree diseases.

Status.—Begun in 1907. Work is in cooperation with the Forest Service at Washington, D. C., Providence, R. I., Spokane, Wash., Denver, Colo., Albuquerque, N. Mex., and San Francisco, Calif.

Results.—Fundamental contributions have been made to the knowledge of about 50 diseases.

To be continued along the same line.

Assigned to George G. Hedgcock, E. P. Meinecke, Jas. R. Weir, W. H. Long, J. S. Boyce, Ellsworth Bethel, E. C. Hubert, and G. G. Hahn.

266. Miscellaneous imported and epidemic tree diseases. Investigation of the white pine blister rust, the chestnut blight, the pitch-pine blister rust, the European-poplar canker, and other imported and epidemic tree diseases, with reference to their control. In the course of work under other projects, attention is called to these diseases. Their life histories are then studied to find weak points for attack, and their range, origin, and means of spread are determined. Under this project the fundamental problems of spread and adaptation of introduced diseases and the problems of susceptibility of native tree species to foreign diseases are studied.

Status.—Begun in 1907. Work is in cooperation with Federal Horticultural Board; also informal cooperation with States, institutions, private firms, and individuals; at Washington, D. C., Providence, R. I., Bell, Md., Arlington, Va., and various field points throughout the United States.

Results.—The real nature and Asiatic origin of the chestnut blight and its manner of distribution have been determined. Many new facts have been discovered regarding the relation of meteorological conditions to this disease. Extensive destruction of advance infections has been accomplished, which is estimated to have retarded the advance of the disease 15 years. The practical utilization of blight-killed trees has been made possible. Resistant and immune Asiatic strains have been discovered. A chinquapin-Japanese chestnut hybrid resistant to the chestnut blight has been developed and is being propagated. Resistant individuals of the American chestnut have been discovered and stock from these is being propagated. Eleven newly imported diseases have been studied and destroyed so far as found. New and decisive methods, involving new symptoms, have been discovered for identifying doubtful cases of white-pine blister rust. All native Ribes tested (about 70 species) have been found susceptible to blister rust. The blister rust has been shown to be apparently taking on new characters and to be apparently more virulent in America than in Europe. Overwintering of viable spores on Ribes has been demonstrated. The distance of spread of spores from Ribes to pines has been shown to be short, making possible the methods of local control now in use. The rust on Ribes in Colorado, at first believed to be the white-pine blister rust, has been shown to be a relatively harmless native rust, with its alternate stage on pinon pine. The work done under this project has resulted in a marked change in the public attitude toward such diseases, involving general recognition of the dangers of importation of ornamental and forest-tree nursery stock.

Future work will be largely limited to studies and development of strains of chestnut resistant to blight, and to further studies of the white pine blister rust.

Assigned to Haven Metcalf, Perley Spaulding, Reginald H. Colley, G. F. Gravatt, and Minnie W. Taylor.

BLISTER RUST CONTROL

Samuel B. Detwiler in charge

267. Control of the white pine blister rust. Local control areas are established in regions where Ribes infection is general. Wild and cultivated Ribes are destroyed in these areas in cooperation with and under legal authority of the States concerned. Specially selected demonstration areas are used to determine the most efficient methods, cost, and practicability of wild Ribes eradication. Eradication of beds of skunk currant and dense wild gooseberry growth by means of various chemicals is being undertaken in a small way. Shipments and reshipments of 5-needle pine stock from foreign and domestic nurseries, known or suspected of being infected are traced and inspected. When the disease is found the diseased trees, and nearby Ribes when necessary, are destroyed by the appropriate State officials; when legally or otherwise possible, the entire shipment is destroyed. Systematic scouting for diseased pines and Ribes also is conducted outside the region of general infection wherever there is a possibility that "spot infections" of the blister rust exist. Eradication of these secondary infections is attempted by removal of all pines or Ribes, or both if necessary, under State authority.

Status.—Begun in 1916. Formal or informal coöperation has been established with all States except Florida, Alabama, Mississippi, and Louisiana, where there are no 5-needle pine interests. In the New England States, New York, Pennsylvania, Wisconsin and Minnesota, control work is done on the basis of one dollar spent from Federal funds for each dollar spent by State and Town authorities. In all cases eradication is done under State authority, the Bureau of Plant Industry assuming responsibility only for locating the disease.

The work is conducted wherever the white pine blister rust occurs or is suspected to be present, particularly throughout the range of 5-needle pines. Inspection of nursery stock and plantations is carried on chiefly in New Jersey, Pennsylvania, Delaware, Maryland, the southern Appalachian region, the Middle West and the far West. Experimental control and demonstration Ribes eradication areas are located in the New England States and northeastern New York. Similar areas will soon be established in Wisconsin and Minnesota.

Results.—Blister rust infection on Ribes is general in the New England States and northeastern New York. Many widely distributed incipient pine infections are beginning to appear as a result of heavy Ribes infection in 1915 and 1916; but the disease has not yet had time to produce severe damage to pine on a large scale. Infected areas vary in size from a few pine trees within a hundred feet of single infected Ribes to over 50 per cent of the pine within a radius of one-half mile from large bodies of diseased cultivated bushes. Strip surveys show that 25 per cent of the native pines in an area of 72 square miles in northern New Hampshire are infected with blister rust, due to wild

gooseberries averaging about 30 bushes per acre. The oldest infection found on this area occurred in 1906. On a strip line 30–7/8 miles long run from Lisbon to Woodsville and Piermont, New Hampshire, 2.4 per cent of the pines were found infected.

During the past season, the results of intensive and extensive scouting in Minnesota and Wisconsin have shown that the disease is firmly established on pine and Ribes in both States. Blister rust was found either on pine or Ribes, or on both hosts, in nine counties in Wisconsin and fourteen counties in Minnesota. In some of these counties it was so generally distributed as to make the possibility of eradication hopeless. The policy of eradication that has been in force hitherto in these States, has been abandoned and in the future the work will be placed on a local control basis, as in the New England States and New York.

In the New England States and New York the work is devoted almost entirely to perfecting cheap and effective methods of destroying wild Ribes; to practical demonstration of these methods on local control areas; and to the encouragement of effective local eradication of Ribes in cooperation with towns, associations, and individuals. During the past year, the interest of these local cooperating agencies has been very encouraging. They have appropriated about twenty-five thousand dollars for the protection of their pines by the eradication of Ribes and the outlook for further cooperation of this sort is favorable.

Experience thus far gained on demonstration and local control areas has definitely proved that under normal conditions, at least 95 per cent of the wild Ribes on a given area can be permanently removed at a cost ranging from 5 cents to $1.50 per acre. Improved methods of locating and uprooting Ribes bushes are responsible for reducing the average labor cost in New England from 44 cents per acre in 1918 to 24 cents per acre in 1919. Intensive scouting showed that no pine infections had taken place on four control areas on which currants and gooseberries were destroyed in 1916 and 1917.

Intensive studies of pine infection centers have been made to obtain data on the distance to which Ribes will infect pine. Under ordinary conditions the removal of Ribes within a distance of 200 to 300 yards of pine will insure its commercial growth.

Various chemicals and sprays are being tested to find a cheap and practical means of effectively killing wild Ribes. Satisfactory progress has been made and the results obtained indicate that dip oil, fuel oil, and possibly sodium arsenite, can be used economically to destroy dense growths of Ribes where the cost of hand-pulling is excessive.

Inspection of nursery stock, pine plantations and general scouting for the disease on pine and Ribes resulted in the location of one diseased planted tree in Michigan and one infected patch of cultivated Ribes in New Jersey. The results of inspecting thousands of planted pine and Ribes in the far western States indicate that this region is free from white pine blister rust. Continued scouting in these States is most important and is being actively pursued. Six violations of the quarantine, prohibiting shipments of pine and Ribes from the States east of and including Minnesota, Iowa, Missouri, Arkansas, and Louisiana, to points west of those States, have been discovered the past season. This shows the possibility of the disease reaching the important pine forests of the west and emphasizes the necessity of strict enforcement of this quarantine.

Future work to be continued along same lines with special effort toward securing removal of currant and gooseberry bushes from the vicinity of valuable pine areas in infected regions before further damage from the blister rust occurs.

Assigned to S. B. Detwiler, Roy G. Pierce, J. F. Martin, A. B. Brooks, G. B. Posey, and E. C. Filler.

BUREAU OF ENTOMOLOGY

L. O. Howard, Chief

FOREST AND SHADE TREE INSECT INVESTIGATIONS

A. D. Hopkins in charge

(From Program of Work of the United States Department of Agriculture for the Fiscal Year 1919.)

FIELD INVESTIGATIONS

268. Insects affecting forest products. To determine the character, cause, and extent of injuries to crude, finished, and utilized forest products and methods of preventing losses; the relative immunity of different species of wood to attack by termites and other insects; the relative efficiency of chemical preservatives in the treatment of cabinet and other woods against attack by termites, powder-post beetles, and other wood-boring insects; the relative efficiency of chemical preservatives and methods against insect attack on wood set in the ground; the character and extent of the damage caused by termites and practical methods of prevention and control; powder-post injury to seasoned forest products; and damage to poles, posts, mine props, railroad ties, and similar forest products by wood-boring insects.

This is a general project, in which, in addition to the investigations conducted by the leaders, some attention is given to the subject by all members of the staff in connection with their regular field work. The data obtained are submitted to the leaders for study, compilation, and publication. The project includes studies of the character and cause of injuries to recently felled trees, saw logs, round timber, rough timber, and other unseasoned crude products; injuries to seasoned rough and dressed lumber and finished wood material; injuries to construction timbers and other timbers and other wood material used in buildings, bridges, railroad construction, mining, etc.; injury to stored oak and hemlock bark for tanning purposes; injuries to medicinal bark, roots, leaves, etc.; and experiments to determine methods of preventing losses; also investigations of insect galls used for dyes, inks, etc., the insects which produce them, and methods of increasing, collecting, and preserving the products. Special attention is given to investigations and advice with reference to crude and finished products used by the Army and Navy. This involves direct relations with the commissary and supply divisions which have been established.

Status.—This project was begun in 1902. The work is in cooperation with manufacturers and utilizers of forest products; also the Bureau of Chemistry in analyzing preservatives, insect galls, etc. Field station located at East Falls Church, Va. Field of operations, United States; and Central and South America, through correspondence.

Results.—The results of extensive investigations and experiments with preservatives on different kinds of wood have shown that a large

percentage of the serious losses hitherto suffered can be prevented. The recommendations and advice of the bureau have been solicited by the commissary departments of the Army and Navy, and in important cases where the advice has been adopted gratifying results in the prevention of losses of valuable crude and finished products have followed. In like manner, the leading manufacturers of vehicles, farm machinery, etc., have sought advice and followed it with most satisfactory results to them. The recommendations based on detailed studies and experiments with poles set in the ground, mine props, railroad ties, telephone and telegraph poles, etc., are being adopted by electrical, mining, and railroad engineers, and a great saving is being effected thereby.

Assigned to A. D. Hopkins, T. E. Snyder, F. C. Craighead, and S. A. Rohwer.

269. Economic investigations of the Scolytid bark and timber beetles of North America. To determine the character and extent of damage caused by these insects to forest growth and forest products, the seasonal histories and habits of the principal species, and practical methods of preventing losses from their attacks.

Procedure.—This is a general project, in which the leader is assisted by other members of the field force in connection with their regular field duties, and includes the collection of material of all stages of the insects and their work, with full field notes on observations relating to seasonal histories, habits, and methods of control, experiments with natural enemies, and verifications of results. These data are submitted to the leader for study, compilation, and publication.

Status.—The work was started in 1890. Cooperation with the Department of the Interior and Forest Service, in the investigation and verification of results of practical control work against the Dendroctonus beetles in the national parks and national forests. The work is conducted from Washington, D. C., and field stations, with field of operations in all the forested areas of the United States.

Results.—The results of the investigations of methods of controlling depredations by bark beetles in the coniferous forests of North America have led to the discovery of practical methods of protecting national, State, and private forests from their most destructive insect enemies. The adoption of the bureau's recommendation based on this discovery has resulted in an estimated saving of not less than $10,000,000 annually in the value of timber protected, at comparatively little cost.

The Dendroctonus beetles have continued to be a menace to the standing pine, spruce, and Douglas fir timber of the Rocky Mountain and Pacific-coast States wherever control measures have not been adopted and carried out to prevent the spread of local outbreaks, and in the aggregate many millions of dollars worth of the best timber has been lost, but wherever the methods that have been determined and advised by this bureau have been adopted and carried out most gratifying results have followed. Especially is this marked in and adjacent to areas where control work has been done in past years in Colorado, Montana, Wyoming, Oregon, and California.

The percentage principle of control has stood the test of another year and appears to be one of the most important practical results attained in the forest-insect work, and much additional confirmatory

data have been secured on the host selection principle as related to the economy of insect control.

Under direction of Dr. Hopkins.

270. Economic study of forest Buprestidae or flat-headed borers. Object and procedure same as for preceding project.

Status.—Work begun in 1904 and carried on at Los Gatos, Cal. (field laboratory); field of operations, United States.

Results.—It has been determined that some of the flat-headed borers are primarily destructive to living trees, while others contribute to the death of weakened trees or are destructive to the wood of living and dead timber, and that a large percentage of the losses can be prevented through a practical application of the information already acquired and published. Special progress has been made in the investigation of seasonal histories and habits of many species of flat-headed borers and methods of controlling them. An example of special interest is the investigation of serious damage to plantation of "Australian" in Florida by a species of flat-headed borer (*Chrysobothris impressa* Fabr.) which normally breeds in mangrove. As a result of the investigation, methods of control have been developed and adopted by the principal growers.

Special progress has been made in the studies of Agrilus beetles on the Pacific Coast and in the development of methods of controlling the more important species. It has been determined that the oak twig girdler (Agrilus angelicus), which kills the twigs and small branches on the live oak in California, can be controlled by collecting and burning the infested twigs.

The menace to the oaks on Long Island, N. Y., by the two-lined chestnut borer (*Agrilus bilineatus*) has evidently been reduced to a minimum through the adoption of the methods recommended in connection with the instruction and demonstration work carried on there during the past two years.

Assigned to H. E. Burke, T. E. Snyder, and W. S. Fisher.

271. Economic study of forest Cerambycidae, or round-headed borers. Object and procedure same as for preceding project, except that this is a special project.

Status.—Work begun in 1904 and conducted from East Falls Church, Va. (field station); field of operations, United States.

Results.—The results of a special study of this class of bark and wood borers have shown that they are far more destructive than was heretofore supposed. Special progress has been made in the acquiring of new information on the seasonal history and habits of a large number of species and in the development of remedies. A result of exceptional value and importance is the successful experiments with poisoned kerosene emulsion and other contact insecticides against the locust borer in some large plantations. This resulted in the killing of from 90 to 95 per cent of the young larvae before they entered the wood, at a comparatively small cost, and showed that plantations of black locust which have heretofore failed on account of the borer can now be successfully maintained, and thus add greatly to the supply of one of our most important wood products.

The oak shade and forest trees of the Southern States have suffered severely from the attack of the Romaleum oak borer in the main trunks and the Prionus root borer in the roots. The special investigations

and experiments carried on have resulted in the determination of many new facts relating to the insects and methods of protecting the trees against their destructive work.

Assigned to F. C. Craighead.

272. **Economic study of beneficial forest insects.** To determine the character and extent of beneficial influences of parasitic and predatory insects, their histories and natural enemies, and methods of propagating and encouraging their beneficial work; and to secure the importation of foreign species and the artificial dissemination of native species.

Procedure.—Same as for preceding, except that this is a general project.

Status.—Work begun in 1903, and carried on at Lyme, Conn., and East Falls Church, Va. (field stations); field of work, United States.

Results.—Many new facts have been determined regarding the principal parasitic and predacious insects which are the natural enemies of injurious insects, and this information has been of special importance in connection with the practical application of artificial methods of control. Special progress has been made in the new feature taken up last year on the investigation of gall insects, *viz.*, to determine the relative value of American galls for dyes and inks as compared with the Aleppo galls of China. The Bureau of Chemistry is assisting in this work by analyzing the various galls submitted by the specialists assigned to the project.

Assigned to A. D. Hopkins, A. B. Champlain, S. A. Rohwer, and Adam Boving.

273. **Bark lice of the genus Chermes.** The determination of systematic and bionomic facts relating to the species of Chermes which infest the bark of coniferous and other forest trees, with special reference to the species involved, their life history and habits, and methods of combating them.

Procedure.—Same as preceding project.

Status.—Begun in 1908.

Results.—It has been found that this class of insects, each species of which lives alternatively on two different species of trees, making galls on the twigs of spruce and infesting the twigs and bark of pine, is of special economic importance. It has been discovered that if nursery and ornamental trees are sprayed with kerosene emulsion at the time new growth starts on the twigs it will protect the trees from damage by this class of insects. Special progress has been made in this line of investigation, especially on the species affecting western conifers, including the discovery of many new facts. Experiments with kerosene emulsion and nicotine sulphate on spruce and pine at Colorado Springs, Colo., showed that both of these contact sprays were effective remedies against the bark and gall lice.

Assigned to A. D. Hopkins, J. H. Pollock, and Jacob Kotinsky.

274. **Insect-control instructions and demonstrations in the National Parks and National Forests.** To give instructions on the essential practical details and to conduct demonstration projects on the control of Dendroctonus beetles in national parks and national forests in accordance with principles and methods recommended by the Bureau of Entomology.

Procedure.—This is a special demonstration and instruction project, in which the Department of the Interior and the Forest Service detail rangers to the Bureau of Entomology to receive instructions from an entomological ranger of this bureau, who has been trained as an expert on the practical details of cruising and locating infested timber and in the application of measures advised by the leader of this project. The instructions relate to (*a*) methods of cruising to locate the infested timber requiring treatment, (*b*) the essential practical details of conducting the work of control and protection against Dendroctonus beetles, (*c*) the inspection of areas in which control work has been done, (*d*) the location of areas requiring treatment, (*e*) estimating the character and extent of insect-killed or infested timber, and (*f*) advice on such other matters pertaining to the practice of forest entomology as may be deemed necessary. All entomological matters except the minor questions that can be handled by the insect-control expert will be referred by him either to a local entomological expert of the Branch of Forest Insects, Bureau of Entomology, or to the chief of the branch at Washington for advice or recommendations. The Bureau pays the salaries of the entomological rangers. The Department of the Interior and the Forest Service pay their traveling and field expenses and also the salaries and expenses of their rangers assigned to the work and the expenses of all cruising and control operations. When the park and forest rangers are sufficiently trained and qualified, they are designated as insect-control rangers and assigned to a national park or national forest to work under the immediate supervision of the park or forest supervisor or superintendent.

The attention to this subject in 1918–19 will be mainly in the line of recommendations and instructions in the Sequoia National Park and Sequoia National Forest.

Status.—Begun in 1913 and conducted in cooperation with the National Park Service and the Forest Service.

Results.—This work has resulted in verifying and demonstrating the practicability and efficiency of the percentage principle of control. The Yosemite Valley is now practically free from damage. Special interest has been aroused among the principal private owners of timber in California, who have requested a survey of the State to ascertain the character and extent of the depredations by Dendroctonus beetles and to develop methods of control. A special informal arrangement between the private owners, the Bureau of Entomology, the Forest Service, and the National Park Service of the Interior Department has also been effected, whereby a representative of the Bureau of Entomology has been charged with the general supervision of the work, the pro rata field expenses involved to be borne by the directly interested private owners and public service.

Assigned to A. D. Hopkins and J. M. Miller.

275. Investigation of insects affecting shade trees and hardy shrubs. To determine (*a*) the general character and extent of damage by insects to the trees and shrubs of public and private grounds, including municipal parks, streets, cemeteries, country roads, private parks, national cemeteries, etc., (*b*) additional facts on the seasonal histories and habits of the insects involved, and (*c*) additional facts on practical methods of prevention and control; to conduct experiments, and finally to give

advice through correspondence, publications, and otherwise, on the principles and methods of control to meet the requirements of specific insects and local conditions.

Procedure.—This is a general project to which members of the regular field and laboratory force give more or less attention, collecting material and studying and identifying insects. The small allotment of funds available for this work renders the field of operations so limited that very little can be accomplished except along restricted lines of investigation. Some informal cooperation with municipalities, Federal and State officials, and owners of private parks and grounds will be invited, looking to their adoption of the most economical and effective methods of prevention and control, the conduct of experiments with new methods, and the verification of results in practice.

Status.—The work was begun in 1915. Much assistance has been rendered, by way of advice through correspondence, in connection with shade-tree problems. The work of the field laboratory at Los Gatos, Calif., has been directed to the investigation of local problems, one receiving special attention being a study of the defoliation of oak shade trees by caterpillars. An aphis on walnut shade trees at Los Gatos, Calif., has proved troublesome in that its attacks result in the pavements and streets becoming slippery by reason of the quantities of honeydew exuded. Spraying the trees with nicotine sulphate proved to be a successful means of eliminating the trouble.

Results.—As a result of extensive instruction and demonstration work on Long Island, N. Y., during the past two years, a serious menace to the hickory and oak shade and forest trees of the island has been effectively removed through the activity of property owners in carrying out the recommended method of cutting and utilizing or otherwise disposing, during the fall, winter, and early spring, of a majority of the trees that died the preceding summer.

Assigned to A. D. Hopkins, H. E. Burke, and Jacob Kotinsky.

LABORATORY INVESTIGATIONS

The work under this group has special reference to original research on the more technical features of the science of forest entomology and has yielded some of the most important results in the line of essential and fundamental information on which to base economic research and practice. For each family of insects studied. The object is to (*a*) determine, classify, and describe the genera, species, and stages of development which are new to science; (*b*) revise and bring up to date the systematic knowledge of all North American species; (*c*) investigate problems relating to anatomy, taxonomy, terminology, and nomenclature; (*d*) determine seasonal histories, food, and breeding habits, geographical distribution, and such other information of a technical nature about the species as is essential to the best success in the investigation and practical treatment of economic problems.

Procedure.—These are special projects, in which specimens of all stages of the insects and their work are collected by the leaders and members of the force in connection with their regular field duties from all parts of the United States or are received by exchange or for identification from all parts of the world. These specimens are labeled, classified, and preserved in a separate collection in the National Museum with the collection of forest insects under the custodianship of the leader. Such

time as can be spared from the regular administrative duties is devoted to a systematic study of the material and the literature on the subject and to the preparation of manuscript for permanent record and publication.

276. Forest and other Scolytidae. Studies begun in 1902 and carried on from Washington, D. C. The results of the systematic work on this group of insects have shown that previous to the leader's work on this group nothing whatever had been known of a large number of the most destructive insect enemies of North American forest trees. The information acquired has made it possible to study their exact economic relations to the trees and to discover practical methods of control and prevention. The value of the results of this work alone may be estimated in tens of millions of dollars toward the practical conservation of the forest resources of the United States. The collections are the largest in the world, and specimens are sent here from many other countries for authentic identification.

Assigned to A. D. Hopkins.

277. Forest and other Buprestid larvae. Studies begun in 1904 and carried on at Los Gatos, Calif. (field laboratory); field of operations, United States. Heretofore practically nothing was known of the systematic characters by which the larvae of various species of this class of insects could be identified, and without this knowledge very little could be accomplished in the study of seasonal histories and habits, and practically nothing could be done toward the discovery of effective methods of control. Special progress has been made in this work in the discovery of new facts of economic importance.

Assigned to H. E. Burke.

278. Forest and other Cerambycid larvae. Studies begun in 1904 and carried on from Washington, D. C. Exceptional progress has been made in the investigation of these larvae. While they are of great economic importance, very little was known about them a few years ago. Now more than 250 species have been identified and a fund of information acquired of great scientific and economic value. Special progress has been made in the preparation of important manuscript for publication.

Assigned to F. C. Craighead.

Investigations are also being conducted on forest Hymenoptera, Lepidoptera, Coleoptera, Diptera, and forest and other Isoptera and Coleopterous larvae.

RESEARCH ORGANIZATIONS WITHIN THE STATES

State Departments, Universities, and Private Agencies

NEW ENGLAND STATES

NEW HAMPSHIRE

NEW HAMPSHIRE STATE FORESTRY DEPARTMENT

J. H. Foster, Acting State Forester. Concord, N. H.

279. Fire protection. (*a*) Brush disposal with reference to cost and efficiency of different methods and effect on reproduction. (*b*) Fire lines—cost of establishment and cost and efficiency of maintenance by different methods.

Information to be obtained during the coming fall and winter.
Assigned to J. H. Foster.

280. **Planting.** Relative cost and efficiency of spade versus mattock for different types of soil cover.
Information to be obtained during the coming spring and summer.
Assigned to J. H. Foster.

281. **Statistical and economic survey of forest resources of New Hampshire.**
Under way.
Work expected to continue one or two years.
Assigned to J. H. Foster.

NEW HAMPSHIRE AGRICULTURAL EXPERIMENT STATION

K. W. Woodward, Forester, New Hampshire College, Durham

282. **Thinning.** Thinning of immature stands of white pine and hardwoods to determine the best methods and financial returns from such thinnings.
Begun by J. H. Foster in 1913. Twenty-six plots have been established in the vicinity of Durham.
The sample plots are measured annually and a preliminary statement of results is now in preparation. Periodic reports are to be made every 10 years. It is planned to extend the experiment to include the thinning of other native species such as spruce.
Assigned to K. W. Woodward.

283. **Growth of exotics.** Rate of growth of various exotics, such as Scotch pine, Douglas fir, European larch, and Norway spruce.
Plantations of these species were started by J. H. Foster in 1913.
Plots remeasured annually. Periodic reports to be published every 10 years. It is planned to extend the experiment to include the trying out of all tree species suitable to New Hampshire climatic conditions.
Assigned to K. W. Woodward.

VERMONT

UNIVERSITY OF VERMONT

Department of Botany, Prof. G. P. Burns, Burlington

284. **Forest reproduction.** A study of natural reforestation in Vermont.
Begun in cooperation with Vermont State Forester A. F. Hawes in 1914, on plans prepared by Hawes. A sample plot 200 feet square was established, with a control plot of equal size, in each of five types of forest. These plots were given different degrees of thinning for the combined purpose of reproduction and increment study (the latter treated in the following project). In each plot two or more sub-plots, each 10 feet square, were staked out and an exact survey including maps was made of each. A permanent record was made of every plant growing on each sub-plot.
These surveys are repeated every year and new maps and records made. A study of these maps and records shows the changes which are taking place.
Assigned to Professor Burns.

285. Diameter growth in forest.

Begun in 1914 in cooperation with the State Forester, on plans prepared by Mr. Hawes. The plots above described were accurately mapped before thinning, the number, size, and location of the trees to be removed being recorded. Individual trees left were numbered and measured.

Comparative records of diameter growth in the thinned and unthinned plots are being kept.

Assigned to Prof. Burns.

286. Eccentric growth. A study of the factors causing eccentric growth, especially the so-called glassy or "red wood" in pine and spruce.

Greenhouse and field experiments are under way to determine the influence of the wind, position, trimming, etc., on diameter growth. An anatomical study and mechanical tests are being made on the wood developed under the various experimental conditions.

Assigned to Prof. Burns.

287. Tolerance of New England forest trees. The immediate problems in hand are:

(*a*) To determine the minimum light intensity required by each species of our forest trees for the production of a slight surplus of organic matter. The source of light used in this work is a National Mazda C lamp equipped with a Nela screen. Two screens are in use, one giving direct and the other diffused light.

(*b*) To determine the effect of different light rays on the development of forest trees. In this work the colored glass produced for MacDougal at the Tucson Desert Laboratory is used. The glass is set in wooden frames each holding 16 panes, 80 panes for each experimental chamber. The four-sided frames are made with 8-inch bases to give greater height and reduce expense. The plants used are pot cultures.

(*c*) To determine the effect of reduced white light on development of seedlings under nursery conditions. The plants are shaded with cheesecloth, using from one to six thicknesses. Special effort is being made to maintain similar moisture conditions in the groups of plants to be compared. Check experiments are also under way in the greenhouses.

(*d*) To determine the water requirement of the more important forest trees and its relation especially to growth in height and diameter. Pot cultures are used in the work.

(*e*) To study the effect of environmental factors on the development of trees. A series of records of the more important factors of the habitats have been kept for several years and the attempt is being made to determine the effect of these factors which together made up the site with the development of the trees grown there. Stations have been established at the State Nursery, in white pine forests near Burlington, in region near the timber line on Mt. Mansfield and on the summit of the mountain above timber line.

Assigned to Prof. Burns.

MASSACHUSETTS

MASSACHUSETTS STATE FORESTER

William A. L. Bageley, State House, Boston

288. Forest survey of State. To determine by strip reconnaissance the amount of forest land by types and size classes in each town, fire damage, insect damage, etc.

Two counties (Worcester and Plymouth) completed and results published: "Forests of Worcester County," by H. O. Cook, and "Forests of Plymouth County," by James Morris.

Another county to be surveyed in 1920.

289. **Cordwood measurements.** The amount of cubical space occupied by wood cut in short lengths and restacked or loose piled.

Completed and results ready for publication under title of "Measurement of Fuel Wood," by H. O. Cook.

290. **Planting.** Experimental plantation on Cape Cod with plots of white, red, Scotch, and Austrian pines, Norway spruce, Douglas fir, and arborvitae, to determine availability of species in poor soil and strong wind exposure.

Plantation completed.

Similar sample plantations to be made in other sections.

291. **Oak volume table.** Preparation of an oak volume table (bd. ft.) for second growth in Massachusetts.

Field work about one-half completed.

292. **Pine weevil control.** Systematic removal each year of weevil-infested shoots in an isolated plantation to see if insect can be controlled.

Work done for two successive years.

To be continued each year as long as necessary.

HARVARD UNIVERSITY.

Bussey Institution for Research in Applied Biology, Forest Hills, Boston, Mass.

Dr. W. M. Wheeler, Dean

R. T. Fisher, Professor of Forestry and Director of Harvard Forest, Petersham, Mass.

I. W. Bailey, Professor of Plant Anatomy, Forest Hills, Boston

Studies at Bussey Institution for Research in Applied Biology

293. **Dendrology.** Manual of the forest trees of China.

Intended primarily for foresters. To be published in English and Chinese.

Assigned to W. Y. Chun, under the direction of Prof. J. G. Jack. Mr. Chun has been voted a Sheldon Traveling Fellowship for 1919–20 to enable him to collect material and data on the forests of China.

294. **Forest entomology.** Oak galls and the insects which produce them.

Under way. To be conducted in the South, Southwest, and California.

Assigned to A. C. Kinsey, under the direction of Prof. W. M. Wheeler. Mr. Kinsey has been voted a Sheldon Traveling Fellowship for 1919–20 for the purpose of collecting and making field observations.

295. **Economic botany (forest products).** Catalog of principal botanical raw products of the world.

A large working collection of economic products is rapidly being brought together. Endeavor is being made to correlate scientific and common names. Catalog to include forest products of both temperate and tropical regions.

Continuing.

Assigned to Prof. Oakes Ames and assistants.

296. Wood technology. Studies of:

(*a*) Cambium of arborescent *Conifers* and *Dicotyledons;* cytological, histological, and physiological.

(*b*) "Fiber" of coniferous and broad-leaved trees.

(*c*) Effects of light, gravity compression, and tension upon the structure of stems and branches.

(*d*) Variations in structure of wood and the principal factors which produce them.

(*e*) Effects of the structure of wood upon its technical properties.

(*f*) Identification of herbarium material and wood of tropical trees. Herbarium material of tropical trees collected by Prof. Whitford, Mr. Curran, and others is identified by members of the staff of Gray Herbarium. Wood sections accompanying these sheets are sectioned and filed under direction of Prof. Bailey for subsequent use in the construction of a key to the principal families and genera of woods.

The studies in wood technology are continuing.

Projects *a-e* assigned to Prof. I. W. Bailey.

Project *f* assigned to Gray Herbarium and I. W. Bailey, in cooperation with Yale Forest School.

Studies Conducted at Harvard Forest, Petersham, Mass.

297. Reproduction cuttings. To test the efficacy of various cutting methods for the reproduction of white pine and chief associated species.

Annual cutting areas under observation and record since 1909. Systems employed: modification of clear cutting and shelter-wood methods. Paper on the reproduction of white pine in preparation.

Continuing.

Assigned to Prof. Fisher.

298. Improvement cuttings. Experiments to determine method, costs, and possibilities of improving the composition and yield of mixed stands by early weeding.

Areas under treatment, including permanent sample plots, since 1912. Paper on "Yield of Volunteer Second Growth," by R. T. Fisher, published in Journal of Forestry, May, 1918.

Continuing.

Assigned to Prof. Fisher.

299. Recovery from suppression. Relation of recovery of suppressed trees to age, site, and extent of release.

Sample plots under observation.

Continuing.

Assigned to Prof. Fisher.

300. Thinning. Permanent sample plot in pure even-aged white pine to accumulate data on the effect of periodic thinning upon yield, etc.

Plot established in 1912. Thinning and records made every five years.

Continuing.

Assigned to Prof. Fisher.

301. Plantations.

Permanent sample plot in plantation of white pine to follow annual progress in height growth, establishment of cover, natural pruning, etc.

Planted in 1909. Records begun in 1913.
Continuing.
Assigned to Prof. Fisher.

302. **Plots in plantation of white pine to determine effect of planting distance upon yield.** Distances used are 3, 4, 5, and 6 feet.
Established in 1916.
Continuing.
Assigned to Prof. Fisher.

303. **Plantations for test of species under various site conditions, in competition with natural reproduction on open and cut-over land; and for test of underplanting.** Comparative value of certain exotic species in reforestation.
Approximately 80 acres planted from 1909 to 1919. Species used: white, Norway, Scotch, and western yellow pines, Norway spruce, European and Japanese larch, and Douglas fir.
Continuing.
Assigned to Prof. Fisher.

304. **Commercial planting: a study of the silvicultural lessons of forest planting in Massachusetts.**
Examination of existing plantations in light of all available data as to establishment, history, etc.
To be completed in summer of 1920.
Assigned to A. H. Richardson, research student, Department of Forestry.

305. **Lumbering.** Collection of cost data on operations in portable mill logging, sawing, etc.
Records filed from classified time sheets. Publication planned.
Continuing.
Assigned to Prof. Fisher.

306. **Measurements.**
Mill tally volume tables for second-growth chestnut.
Completed but not published.
Mill tally log scale for white pine.
Completed but not published.

307. **Growth study.** A yield table for second-growth hardwoods in central New England.
Fifty sample plots measured and computations now in progress.
Assigned to J. N. Spaeth research student, Department of Forestry.

Studies conducted at both the Bussey Institution and the Harvard Forest

308. **Forest entomology.** Studies of *Hylobius pales* in relation to injuries to conifers.
Field, laboratory, and library investigations in progress.
To be completed in autumn of 1920.
Assigned to H. B. Pierson, under direction of Professor C. T. Brues, and R. T. Fisher.

MASSACHUSETTS AGRICULTURAL COLLEGE

Department of Forestry. William D. Clark, Professor of Forestry, Amherst

309. **Improvement cuttings on the Mt. Toby State Demonstration Forest of 754 acres looking toward the development of a more productive forest.**

Removal of blighted chestnut begun October, 1916. To date 750 cords of wood, 3496 railroad cross-ties, and 28,586 linear feet of telephone poles have been removed.

Cutting proceeding, looking toward the entire elimination of chestnut from the forest and the substitution of white and red pine by planting and natural seeding.

Assigned to W. D. Clark, Professor of Forestry and head of the Department of Forestry at Massachusetts Agricultural College in charge.

CONNECTICUT

YALE UNIVERSITY

Yale Forest School, J. W. Toumey, Dean, New Haven

Silvicultural Research

310. Yield of coniferous plantations in southern New England; particularly of white and red pines in pure and mixed stands, but including other conifers as opportunity offers.

Twenty-seven permanent sample plots, from 1/4 to 1 acre in size, were established in young stands in 1917 and 1918, and the essential measurements taken. The individual trees will not be numbered, this refinement being unnecessary to accomplish the purpose of the experiment. Four qualities of site—1, 2, and 3 (well drained) and 1*b* (bottomland); and six species—white, red, Scotch, and western yellow pines, Norway spruce, and European larch—are represented. The plots are located as follows: New Haven County, Conn., plots 4–6 and 11–29, inclusive; Union, Tolland Co., Conn., plots 101, 102, 109, 110; Rainbow, Hartford Co., Conn., plot 100.

Ten or fifteen new plots per year will be established in 1919 and subsequent years until the various sites and the range of coniferous species suitable for planting in southern New England have been covered. In 1922 remeasurement of the plots first established will be started. Time for completion, 60 years.

Assigned to Prof. R. C. Hawley.

311. Thinning: results on bottomland and swamp sites (disappearance of chestnut makes thinning experiments on upland of small consequence in southern Connecticut).

One set of 4 plots aggregating seven-eights acre was established and measured in 1916–17 at Maltby. Two other series at Saltonstall and Wapowaug reservoir are approximately one-third complete. Location and plot numbers: New Haven Co., Conn., plots 1, 2, 3, 8, and 9. Permanent plots, variously thinned, with check plots; individual trees numbered and measured.

Only the three sets of plots are planned. They will be established within two years. Time for completion, 20 to 30 years.

Assigned to Prof. R. C. Hawley.

312. Thinning: results on upland sites.

Five plots (including check plot) aggregating 0.45 acre were established at Ansonia, New Haven Co., Conn., in 1906, and remeasured in 1911 and 1916. Individual trees numbered and measured.

To be remeasured in 1921. Time for completion, 30 years.

Assigned to Prof. R. C. Hawley.

313. Thinning: results in naturally reproduced stands of white pine.
Three sets of plots, with check plots, established as follows: One set (plots 601–604, inclusive, aggregating 1 1/4, acre) in 1905, at Keene, N. H., in 35–40-year-old pine; two sets (plots 104–108), inclusive, aggregating 1 1/8 acres) in 1916, on the Geo. Myers estate, Union, Conn., in 25 and 60-year-old pine. Individual trees numbered and measured; thinnings have been made. In one series at Union, Conn., selected trees were pruned up 17 feet.

The established plots to be thinned and remeasured frequently. Time for completion, 30 years.

Assigned to Prof. R. C. Hawley.

314. Thinning: results in chestnut and oak sprout groups while in sapling stage.
Three plots (Nos. 398, 399, and 400) of one-tenth acre each were established at Ansonia, Conn., in 1906. Plot 398 left intact, the others thinned. Important sprout groups indicated on crown cover diagrams. All reproduction tallied. Age of sprouts at date of establishment, 4 years. Trees measured and numbered in 1916.

To be remeasured in 1921. Time for completion, 30 years.

Assigned to Prof. R. C. Hawley.

315. Reproduction and increased growth in hardwood stands after heavy thinnings.
Seven main plots and 63 reproduction plots established at Maltby Park, New Haven, Conn., in 1906, and remeasured in 1911 and 1916. Individual trees numbered and measured, reproduction tallied. Main plots numbered 321–327 and reproduction plots 328–390, inclusive.

To be remeasured at 5-year intervals. Time for completion, 20 to 30 years.

Assigned to Prof. R. C. Hawley.

316. Pruning: effect of early pruning of live limbs upon the height growth of planted white pine, with the purpose of developing the best methods of pruning.
A permanent plot (plot No. 11) 1 acre in size was established in New Haven Co., Conn., 1/4 being left unpruned and the remainder to receive the following treatment: selected trees should be pruned every three or four years, removing several whorls of live branches at each pruning, until a 17-foot clear log is produced. In March, 1917, 192 of the best dominant trees spaced 12 to 20 feet apart were pruned. All but the last three or in some cases the last two whorls of live branches were removed. This was too heavy a pruning as height measurements taken in the winter of 1919 indicate.

Trees.	Number.	Annual height growth in feet. 1915.	1916.	1917.	1918.
Pruned	112	1.87	2.13	1.45	1.43
Unpruned	169	1.53	1.75	1.95	2.13

At least two more prunings will be needed to secure a 17-foot length. Another plot will be established to determine how heavy a first pruning may be made and not injuriously affect the height growth. Time of completion, 10 to 15 years.

Assigned to Prof. R. C. Hawley.

317. Reproduction of white pine stands under the shelterwood system. Three main sample plots aggregating 1.05 acres and 11 reproduction plots were established at Keene, N. H., in 1905 and remeasured in 1909 and 1915. Plots numbered 605–610 and 612–619, inclusive. One main plot (605), in stand which had been heavily thinned in 1904, was cut clean in winter of 1912–13. Another (612) was given a reproduction cutting in the winter of 1913–14. The third (614) is yet untreated. Age, all plots, in 1905, 50 to 55 years.

To be remeasured in 1920. Time for completion, 20 years.

Assigned to Prof. R. C. Hawley.

318. Natural reproduction of white pine from adjoining seed woods. Plot (No. 611) established at Keene, N. H., in 1905 and remeasured in 1909 and 1915.

To be remeasured in 1920. Time for completion, 11 years.

Assigned to Prof. R. C. Hawley.

319. Diameter growth of individual Liriodendron tulipifera trees. Three individual trees (plot No. 316, Maltby Lake tract, New Haven) numbered and measured in 1904 and remeasured in 1909 and 1919.

Time for completion, 20 years.

Assigned to Prof. R. C. Hawley.

320. Early development of mixed hardwood sprout stands. Four plots (Nos. 317–320, inclusive) established at Maltby Lakes, New Haven, in 1904, and remeasured in 1909, 1916, and 1919. Plots each 1 chain square.

Time for completion, 20 years.

Assigned to Prof. R. C. Hawley.

321. Production in balsam swamps after cutting. To study amount and cause of loss of standing trees and progress of reproduction.

A 2-acre permanent plot (Nehasane Park Association, No. 201) was established in Herkimer Co., N. Y., in 1916, and measured in 1917, 1918, and 1919. Individual trees numbered and measured.

To be remeasured at frequent intervals noting particularly amount and cause of loss of standing trees and progress of reproduction.

Assigned to Prof. R. C. Hawley.

322. Investigation of gray birch in its effect upon the regeneration of white pine. This investigation develops a method for determining the average chemical light intensity under stands of different degrees of density. The conclusions are that the slow growth of white pine under dense stands of gray birch is primarily due to root competition and not to diminished light as heretofore believed.

Assigned to Prof. J. W. Toumey.

323. Tolerance. A project is under way having for its purpose a better understanding of tolerance with studies based upon instrumentation.

Assigned to Prof. J. W. Toumey.

324. Silvical studies. Studies are projected having for their purpose the investigation of

climatic and soil factors in relation to pure, even-aged stands on a number of our permanent sample plots.
Assigned to Prof. J. W. Toumey.

Research in Lumbering

325. Wholesale lumber prices during the war period, 1913–1918.
Results published under the title of "Prices of Lumber," by R. C. Bryant, Industrial Examiner, Forest Service. War Industries Board Price Bulletin No. 43, 1919. Published in cooperation with the Forest Service.
Assigned to Prof. R. C. Bryant.

Technological Research

326. Mahogany and some of its substitutes.
This research has for its object the development of a descriptive key based on gross and lens characters. See contributions from the Yale School of Forestry, No. 11.
Assigned to Prof. S. J. Record.

327. Stored or tier-like structures of certain dicotyledonous woods.
See contributions from the Yale School of Forestry No. IV.
Assigned to Prof. S. J. Record.

328. The woods of the Zygophyllaceae.
Although one paper on this subject has already been published in Scientific American Supplement, work is being continued with the expectation of a comprehensive paper in the autumn of 1919.
Assigned to Prof. S. J. Record.

329. Woods of the Leguminosae.
Research on the woods of this family, particularly species from tropical regions, have been under way for some time.
Assigned to Prof. S. J. Record.

330. Studies on various groups of tropical American woods.
Results will probably appear in connection with a proposed book on the forests of tropical America.
Assigned to Prof. S. J. Record.

Research in Tropical Forestry

331. Tropical forests and the war.
See "Tropical Forests and the War," by H. N. Whitford, Journal of Forestry, May, 1918; Vol. 16, No. 5, pp. 507–522.
Assigned to Prof. W. N. Whitford.

332. The structure and value of the Parana pine forests of Brazil.
See contributions from the Yale School of Forestry, No. 3.
Assigned to Prof. W. N. Whitford.

333. Tropical forest products.
See Encyclopedia Americana.
Assigned to Prof. W. N. Whitford.

334. The forestry report of the Guatamala-Honduras Economic Survey Expedition.
This report has been prepared and will appear as a publication later on.
Assigned to Prof. W. N. Whitford.

335. Forests of South America.

Progress has been made in assembling the information collected for this publication. A preliminary forest map of South America has been completed which shows the forest regions of the continent and divides these into possible commercial areas.

Assigned to Prof. W. N. Whitford.

Miscellaneous Research

336. Increment and losses over the entire area of the western yellow pine type, Coconino and Tusayan National Forests, with methods of determining these factors, the development of a method by which the area occupied by different age classes can be practically determined for a western yellow pine forest of mixed age classes, the factor of density of stocking or empirical (actual) yield may be determined by using a "normal" yield table, a stand table and total estimates for the type, the future yield of the forest can be computed for the next 200 or 300 years.

Method completed. Application to Coconino and Tusayan National Forests completed September, 1919. See Working Plan for Coconino and Tusayan National Forests (MSS.) Forest Service, Albuquerque, New Mexico.

Assigned to Prof. H. H. Chapman.

337. Damage to western yellow pine reproduction by sheep grazing and its effect upon forest management.

Final conclusions practically completed by study planned and executed in fall of 1919 on Tusayan and Coconino National Forests, Arizona. See reports by Westvelt and Kimball, and studies by Pearson.

Assigned to Prof. H. H. Chapman.

338. The forests of British Columbia.

See "The Forests of British Columbia," by H. N. Whitford and R. D. Craig. Commission of Conservation, Ottawa, Canada, 409 pages, 1919.

Assigned to Prof. W. N. Whitford.

Osborn Botanical Laboratory, Prof. George E. Nichols, New Haven

339. Ecological survey of the vegetation of Connecticut.

Begun in 1910 and carried on intermittently since that time. Publications: "The Vegetation of Connecticut" (series), as follows:

I. Phytogeographical aspects. Torreya 13, 89–112, f. 1–6, 1913.

II. Virgin forests. Torreya 13, 199–215, f. 1–5, 1913.

III. Plant societies on uplands. Torreya 14, 167–194, f, 1–8, 1914.

IV. Plânt societies in lowlands. Bull. Torrey Club 42, 169–217, 1915.

V. Plant societies along rivers and streams. Bull. Torrey Club 43, 235–264, f. 1–11, 1916.

VI. The plant associations of eroding areas along the seacoast. Bull. Torrey Club 47 (in the press), 1920.

VII. The plant associations of depositing areas along the seacoast. Bull. Torrey Club 47 (in the press), 1920.

Also the following: Summer evaporation intensity as a determining factor in the distribution of vegetation in Connecticut. Bot. Gaz. 56: 143–152, 1913.

A bulletin on "The Vegetation of Connecticut" to be prepared as result of field work ending this summer.

Assigned to Prof. G. E. Nichols, under auspices of Connecticut State Geological and Nat. Survey.

340. Ecological survey of the Penobscot Bay region, Maine.
This is a continuation of work begun in 1913 and partially treated in the following publication: "The vascular flora of the eastern Penobscot Bay region, Maine," by Albert F. Hill, Proc. Portland Soc. Nat. Hist. 3: 199–304, f. 1–6, 1919.

Additional field work in the summer of 1920 is contemplated by Mr. Hill.

Assigned to Albert F. Hill.

MIDDLE ATLANTIC STATES

NEW YORK

CORNELL UNIVERSITY

New York State College of Agriculture

Department of Forestry, R. S. Hosmer, Professor of Forestry, Ithaca

341. Volume, growth, and yield studies. To collect and present growth data in such form that the probable yield can be predicted for given species, on given sites, for given times in the future, and under a given system of management.

Work begun May 1, 1919.

To begin with red pine and red spruce in New York State. Object of preliminary studies, to improve present methods of measuring growth. Next, the influence of site factors on growth will be studied. Study to be of individual trees and stands, and by both temporary and permanent sample plots.

Assigned to John Bentley, Jr., Professor of Forest Engineering, and B. A. Chandler, Assistant Professor of Forest Utilization.

SYRACUSE UNIVERSITY

New York State College of Forestry, F. F. Moon, Acting Dean, Syracuse

Silviculture

342. Knot zones and spiral in Adirondack red spruce. To determine amount suitable for airplane stock and influence of growth in virgin forest on cleaning of bole and direction of fiber.

Work carried on two months in summer of 1918. Results published in "Knot Zones and Spiral in Adirondack Red Spruce," by Edward F. McCarthy and Raymond J. Hoyle, in Journal of Forestry, Vol. 16, No. 7, Nov., 1918, pp. 777–791.

Study of spiral will be extended to second growth as opportunity offers.

Assigned to E. F. McCarthy and R. J. Hoyle.

343. Reproduction on cut-over lands in the Adirondacks. To determine relation of various conditions of cutting on reproduction of pulp species on the several natural types of forest.

Work begun in 1917 (July) using strip method followed by a square rod sample plot (3 to the acre) for reproduction count. Height increment studies made by measurement of nodes and diameter increment on diameter limit cuttings. Published: "Production of Pulp on Balsam Lands," Paper, Oct. 23, 1918. Data on accelerated growth and

reproduction in hardwood type read before New York Section of Society of American Foresters and sent to the Journal of Forestry for publication.

The result of this study has directed the investigators to the need of more detailed information concerning the hardwoods which is planned for the coming year.

Assigned to E. F. McCarthy and R. J. Hoyle.

344. **Site studies of planted species.** To determine height and diameter growth and pruning, with purpose of standardization of site and determination of values in site factors.

Work begun spring of 1918; two permanent sample plots established one in 6′ x 6′ Scotch pine, the other in 6′ x 6′ Norway pine. One sample plot established in November, 1918, in 6′ x 6′ western yellow pine. Height increment and pruning studied by a measurement of nodes.

Diameter increment to be obtained by measurement of the permanent plots at 5-year intervals. Present data to be correlated with those collected later. Work to be extended and new plots established as rapidly as possible.

Assigned to H. C. Belyea.

345. **Studies of forest conversion.**

(*a*) Yellow birch in the Adirondack and Catskill regions of New York State. To determine relation of this species to production of softwood in northern forest of New York; improved methods of utilization; creation of market for future second growth; pathological factors controlling species; relation to forest animals; importance relative to other hardwood species.

Reproduction data already collected in 1917. Summer's work with field party, 1919.

Following the completion of the study of yellow birch work will be extended to other hardwood species as the necessity for it is made evident by the birch study; conversion plantations will be made under typical conditions for each type.

Assigned to heads of Departments of N. Y. State College of Forestry under direction of College Committee on Research.

Forest Botany and Pathology

346. **White pine blister rust.** Field investigations to determine the conditions which influence or control the spread of the disease, *viz.*, dispersal, viability, possibility of overwintering upon Ribes, etc.

Work carried on during the field season of 1918 in Lewis, N. Y. The investigations were continued in 1919.

Assigned to Dr. Leigh H. Pennington.

347. **Pathology of yellow birch in New York State.** This is a part of the cooperative study of yellow birch of the College.

Experimental work was begun in the summer of 1916.

Assigned to Dr. L. H. Pennington and Dr. Alfred H. W. Povah.

348. **Fungi of the seed and seedling of Pinus strobus.** A study to determine the mycological flora with a view to obtaining data on the species concerned with mycorhiza, damping-off, etc.

Preliminary studies are under way.

This study will be continued this summer.

Assigned to Dr. A. H. W. Povah.

349. **Stereums associated with timber decay.** To determine something of the nature, life history, and physiology of stereums.
Work being carried on as subject for thesis.
Assigned to Mr. Don M. Benedict.

350. **A survey of the fungous flora of the forests of the State.** To determine the frequency and distribution of the fungi which cause disease, timber decay, or form part of the forest floor in New York State Forests.
Data have been collected for the past several years.
Considerable time will be required for this project.
Assigned to all members of the Dept. of Forest Botany and Pathology.

Dendrology and Wood Technology

351. **Trees of New York State, indigenous and naturalized.** A bulletin to contain about 130 plates drawn directly from nature, with legend accompanying each plate, together with tabulated information covering each species. The bulletin will also contain a certain amount of descriptive botany, keys to families, genera and species, a glossary, etc.
Plates complete. Manuscript in course of preparation. Should be ready for the press May, 1920.
Assigned to H. P. Brown.

352. **An anatomical study of Betula lutea.** A complete anatomical survey of yellow birch including seed, seedling, bark, wood, leaves, seasonal growth, fiber lengths, etc., together with phenological observations.
Work was started in the summer of 1919.
To be continued this summer.
Assigned to H. P. Brown, Mr. Cuno, and others.

353. **Microscopical atlas of the commercial woods of the United States.** The work will include three plane drawings of the wood of the more important commercial species with minute descriptions and keys for identification.
The work was started in September 1919. Part of the plates are complete.
Assigned to C. C. Forsaith.

354. **Fiber yields from American woods.** (*a*) The bearing of the wood ray on pulp yield. A correlation of the fluctuation in pulp yield between species with the volume of the wood rays. (*b*) Other problems pending.
Assigned to Mr. DeSmidt and H. P. Brown.

355. **Microscopic atlas of commercial Philippine woods.** An anatomical and taxonomic study of Philippine woods including photo micrographic and keys for the determination of species. I. Philippine Dipterocarpaceae.
The work was started in January, 1920.
Assigned to L. J. Reyes and H. P. Brown.

356. **Microscopic atlas of commercial Chilean woods.** An anatomical and taxonomic study, including photo micrographs and keys for the determination of species.
Work was started in January, 1920.
Assigned to Lawrence Lee.

357. The ecological morphology of some alpine plants. An interpretation of certain structural features of alpine shrubs.

Work was started in November 1919. Paper ready for publication.

Assigned to C. C. Forsaith.

Forest Policy

358. A study of forest policy. To analyze and classify the efforts of the United States and the States to establish forest policies, to bring about a better understanding of fundamental principles and more uniform legislation in as far as such a study would tend to forward those objects.

Begun in 1906; outline printed for class used in 1907; the extended study is in manuscript.

Manuscript to be reviewed and published in 1920. The principal place of work is at Greensboro, Ga., but it is expected that a part of the work will be done at Syracuse, N. Y., New Haven, Conn., and Washinton, D. C.

Assigned to Courtland S. Winn and Alfred Akerman.

Experiments in Kiln Drying of Lumber

359. The kiln drying of yellow birch. Experiments to determine suitable condition of temperature, humidity, and circulation for the drying of this species, with special reference to the time consumed in drying, the amount of steaming, its frequency and effect on the lumber. Supplementing this work, will be investigations on the steam penetration, coloration of sapwood, per cents of shrinkage, methods of piling and their relation to speed of drying, etc.

Steaming and coloration experiments were started in 1918–19 by R. J. Hoyle. Kiln drying work now under way.

Similar work will be undertaken with maple, beech and other hardwoods native to New York State.

Assigned to H. L. Henderson.

Department of Forest Entomology

360. Studies of the successions of insect forms bred from dying, dead and decaying hickory.

Work begun during summer of 1915 and carried on during the past three years in field and insectary. Field data completed and MS well under way.

Assigned to W. W. Blackman and Harry P. Stage.

361. Studies of the insects affecting yellow birch, Betula lutea. Insects affecting (*a*) reproduction, (*b*) seedling, (*c*) sapling and pole stage, (*d*) tree stage (standards and veterans), and (*e*) insects bred from dying, dead and decaying wood.

Field studies in the Adirondacks during summer of 1919. Insects bred from wood and catkins in insectary during winter of 1919–20.

Work to be continued afield during next two years. Insects affecting reproduction to be completed during coming year.

Assigned to Prof. Carl J. Drake.

362. Ecological studies of the Hemiptera in vicinity of Cranberry Lake, New York.

Work carried on during one summer. To be completed another summer.

Assigned to Prof. Carl J. Drake.

Land Classification in New York State

363. **Land classification.** The problem involves: (*a*) the determination of criteria for a classification of land, and (*b*) the outlining of a system of land classification applicable to New York State, and the development of methods for surveys and reports, with a general compilation of data.

Study of available literature and collection of data to be commenced this year. Direct field investigation as opportunity permits.

Assigned to O. M. Porter, Department of Forest Engineering.

Forest Zoology

364. **A study of the productiveness of animal crops in forest management.** To estimate the relative productivity and economic importance of annual animal forest crops in forest management.

A statistical and comparative study of the productiveness of forests in fish, game, food, grazing and other annual crops of forest food animals, and the comparative value of financial returns from this source. A preliminary study of meat production has been completed and awaits publication.

It is intended that this investigation be extended to other animal crops than food.

Assigned to Dr. Charles C. Adams.

365. **The ecology of the timber line on Mount Marcy in the Adirondacks.** To determine the conditions of life at the timber line.

A field party equipped with meteorological instruments made records during August 1919, in the vicinity of the timber line on Mount Marcy. The members of the party were Mr. Barrington Moore, Dr. Norman Taylor, Dr. George P. Burns, Dr. Chas. C. Adams and Professor T. L. Hankinson. A report is in preparation on both the vegetation and the animals.

It is planned to continue this investigation.

This is a cooperative investigation conducted by the following organizations and their representatives: Mr. Barrington Moore, President of the Ecological Society of America (in charge); Dr. Norman Taylor, Brooklyn Botanical Garden; Dr. George P. Burns, Vermont Agricultural Experiment Station; and Dr. Charles C. Adams and Professor T. L. Hankinson, representing the Roosevelt Wild Life Forest Experiment Station, of the New York State College of Forestry.

366. **The relation of summer birds to the western Adirondack forest.** To determine the status of birds in the ecology of the Adirondack forest.

A summer (1916) was spent living in the field making observations on the relation of the birds to different kinds and conditions of the forest. A detailed census was made of the density of the population of breeding birds in different kinds of forest. The report on this subject entitled, "The Relation of Summer Birds to the Western Adirondack Forest," has been prepared by Professor P. M. Silloway, and awaits publication.

Similar studies are contemplated in the eastern Adirondacks.

Assigned to Professor P. M. Silloway.

367. **Fish cultural management of a forest park for recreational, educational and food production.**

This investigation has been conducted for two seasons (1918–19)

in the Palisades Interstate Park, on the Hudson River. A report entitled "A Preliminary Report on a Fish Cultural Policy for the Palisades Interstate Park" has been published in the Trans. of the Amer. Fisheries Society, Vol. 48, pp. 193–204, 1919, by Chas. C. Adams, T. L. Hankinson, and W. C. Kendall (in cooperation with the U. S. Bureau of Fisheries). Other reports are in preparation.

It is expected that these studies will be ex[illegible]d to all the waters of this 40,000 acre Park.

Assigned to Dr. Chas. C. Ad[illegible] Hankinson, assisted by Dr. W. C. Kendall [illegible] Bureau of Fisheries) and in cooperation w[illegible] Palisades Interstate Park.

368. The control of m[illegible] fish in a fo[illegible] park. To determine the extent of mosquit[illegible] in a bathing lake in a forest recreational park.

Two months summer [illegible]d work has been made by Dr. J. Percy Moore for the College, working in cooperation with the Commissioners of the Palisades Interstate Park and the U. S. Bureau of Fisheries. A preliminary report entitled "Suggestions and Recommendations for the Control of Mosquitoes and Blood-Sucking Leeches in the Palisades Interstate Park" has been prepared.

The study will be continued.

Assigned to Dr. J. Percy Moore of the University of Pennsylvania.

369. The control of blood-sucking leeches in a forest recreational park. To devise means for reducing the numbers of blood-sucking leeches in a large bathing lake.

Two months of field study and experimentation have outlined the main features of the problem and various means of control are being tested. This investigation is being made by Dr. J. Percy Moore of the University of Pennsylvania, for the College in cooperation with the Commissioners of the Palisades Interstate Park and the U. S. Bureau of Fisheries. A preliminary report has been prepared in connection with the studies in the control of mosquitoes.

The investigation will be continued.

This investigation has been conducted by Dr. J. Percy Moore, of the University of Pennsylvania, our leading authority on leeches.

370. The water bloom of forest park lakes in relation to recreation and fish culture.

The field work covered the most important waters of the Palisades Interstate Park. The report is well under way presenting the results of the field work and a summary of the control methods used for blooms, including the influence of chemical methods on the fish.

It is highly desirable that further field studies and experiments be made and this is under consideration.

This problem has been investigated for the College, in cooperation with the Commissioners of the Palisades Interstate Park by Dr. Gilbert M. Smith, of the University of Wisconsin, a specialist on these bloom organisms.

371. The fish cultural management of Oneida Lake. To formulate a system of management for large forest lakes, similar to a system of

silvicultural management, in order that forest waters may be made to produce an annual income.

Considerable field survey work has been done on various phases of the problem during the past five years. The food and feeding habits of fish, with special reference to mollusca, have been studied by Frank C. Baker and have been published as a Technical Pub. No. 4, "The Relation of Mollusks to Fish in Oneida Lake," pp. 1–366, 1916. Quantitative studies of the smaller food animals have resulted in a second volume, Technical Pub. No. 9, "The Productivity of Invertebrate Fish Food on the Bottom of Oneida Lake, with Special Reference to Mollusks," pp. 1–264, 1918. These studies have shown the importance of mollusks as fish food. Other phases of the fish problem have been published by Adams and Hankinson as, "Notes on Oneida Lake Fish and Fisheries," Trans. Amer. Fisheries Soc., Vol. 45, pp. 154–169. Studies of the parasitic diseases of the fish have been made, in cooperation with the U. S. Bureau of Fisheries, by Dr. Henry S. Pratt, of Haverford College, which have resulted in a MS. entitled, "Preliminary Report on the Parasitic Fauna of Oneida Lake."

Considerable progress has been made on a general report on "The Ecology and Economics of Oneida Lake Fish," by Charles C. Adams and T. L. Hankinson.

At present the main effort is being made to complete the reports now in preparation.

The general problem has been in charge of Dr. Charles C. Adams.

Specialists who have been working on various phases of the work have been indicated above. This work was begun by the Department of Forest Zoology of the College in 1914, and with the establishment of the Roosevelt Wild Life Forest Experiment Station, in 1919 this work has been continued by this Station, in cooperation with the U. S. Bureau of Fisheries.

BEAVERKILL FARMS, ULSTER COUNTY

Richard H. D. Boerker, Forester, Box 42, Mt. Tremper, N. Y.

372. A qualitative study of Catskill Mountain vegetation.

Begun in 1917. Formations, associations, and species are being determined. About 200 species identified.

Present study to be completed by 1921; will be followed by meterological measurements in the different formations.

373. Reforestation of lands too poor for farm use: Determination of species best suited to different localities.

Begun in 1916. A steep southern exposure was reforested with about 5000 Norway pine furnished by the State Conservation Commission in 1916 (April). Over 99 per cent alive in April, 1919. Making excellent growth. A wet, rocky pasture of about 2 acres was reforested with 3000 Norway spruce furnished by the State about the same date. About 95 per cent alive. Total cost in both cases $10 per acre. A number of minor experiments are being conducted to determine possibility of acclimating western yellow pine, Douglas fir, and Engelmann spruce, all from the Rocky Mountains.

To be continued indefinitely. Growth measurements to be made at 5 year intervals.

374. **Management.** To convert a poor second growth of hardwood sprouts (poplar, maple, birch, oak) into a high forest of spruce or pine. Attempt to be made to harvest material at a profit.

Begun in 1918. Present stand averages about 25 cords per acre of trees 1"–6" in diameter, with two or three larger trees per acre. Area of about 3 acres (mostly poplar) has been cleared and poplar disposed of at a profit. Reforestation in fall of 1919 with Norway spruce.

To be continued. Sale of wood expected to cover all costs, including reforestation. About 150 acres can be treated in this way. Object of this and other projects is to build up a profitable farm forest on a continuous yield basis.

PENNSYLVANIA

PENNSYLVANIA DEPARTMENT OF FORESTRY

Gifford Pinchot, Commissioner of Forestry, Division of Forest Investigations, J. S. Illick, in charge, Harrisburg

General

375. **Pitch pine in Pennsylvania.** To study characteristics and occurrence, prepare reliable growth, yield, and volume tables, enumerate chief enemies, state local silvical peculiarities, determine quality of the wood, list the uses of the wood, and predict possibilities as a timber tree of the State.

Investigation begun in 1912. Special attention given to the study since spring of 1918. Field of work throughout the State, but especially about Mont Alto, Clearfield, Snowshoe, Bedford, and the Pocono region.

Field work almost completed. Report in preparation.

376. **Chestnut oak in Pennsylvania.** To study range and occurrence prepare accurate growth, yield, and volume tables, ascertain principal silvical characteristics, find out extent to which it is naturally replacing chestnut, and determine successful methods of artificial propagation.

Begun in 1906. Preliminary discussion in reports of Pennsylvania Department of Forestry.

To be continued. Study should be completed within a year.

377. **Basket willow culture.** To increase the production of home-grown rods for basket making, and to bring into use land not now used for any other purpose.

Many experimental holts established on State forests. First production of commercial rods in 1918 from earliest plantings. Investigations at Mont Alto, Caledonia, Pine Grove, Greenwood, Lancaster Valley, Nittany, Grays Run, Ligonier, and Buchanan.

To induce private owners to bring cold, wet, and neglected land into this kind of cultivation. To stimulate basket making by inmates of charitable and penal institutions, and to establish this industry in private homes. To use the areas proposed to be planted on State forests as an object lesson to start the industry generally.

378. **Forest tree distribution.** To ascertain the distribution of the native forest trees of the State; to obtain fuller data concerning their occurrence and their silvical characteristics; to determine the closeness of the correlation between the site factors and the silvical requirements of each species.

Begun in 1895. Systematic plan of procedure outlined in 1912. Collection of data almost complete. General report on the distribution included in Pennsylvania Department of Forestry, Bulletin 11, "Pennsylvania Trees," by J. S. Illick, 1914.

It is planned to publish a bulletin containing outline maps showing the distribution within the State of all the native trees and a discussion of the important silvical peculiarities.

Seeding

379. **Direct seeding.** To determine the possibilities of direct seeding of incompletely stocked forest areas.

Begun in 1902. Continued intermittently to date on selected State forests in various parts of the State. Spot planting and broadcasting have been tried. Species used were: black walnut, pignut hickory, red oak, white oak, chestnut, wild black cherry, sugar maple, basswood, white pine, pitch pine, red pine, Douglas fir, Scotch pine, and Norway spruce.

To be continued.

380. **Source of seed supply.** To ascertain the influence of locality upon the quality of the seed, and the transmission of characteristics through the seed.

Experiment begun in 1910 with Pacific Coast and Rocky Mountain varieties of Douglas fir. Repeated in 1919. Also began experiment with western yellow pine seed from California and Colorado. Also scotch pine from Finland, Riga district, and Germany.

To be continued and extended to cover more species.

Planting

381. **Planting of native hardwood species.** To ascertain the best and most economical methods of establishing and developing stands of native hardwood species on specified sites.

Begun in 1899. Plantings scattered over numerous State forests. The following tabulation gives the total number of each species planted to date (January 1, 1919) and the year when the first plantation of each species was established:

Species.	Number Planted.	Year of Earliest Planting.
Red oak	395,927	1910
White ash	381,733	1905
Honey locust	103,610	1907
Sugar maple	99,114	1910
Wild black cherry	64,340	1910
Black walnut	63,034	1906
American elm	56,382	1909
White oak	33,550	1905
Carolina poplar	25,945	1899
Black locust	10,900	1904
Rock oak	3,350	1905
Chestnut	3,000	1905
Shellbark hickory	2,950	1907

To be continued on a much larger scale than in the past.

382. **Planting of native coniferous species.** To ascertain the best and most economical methods of establishing and developing stands of native coniferous species on specified sites.

Begun in 1902. White, red, and pitch pines are the principal species used. Work conducted on State forests in all parts of the State. The following tabulations gives the total number of trees of each species planted to date (January 1, 1919) and the year when the first plantation of each species was established:

Species.	Number Planted.	Year of Earliest Planting.
White pine	20,669,172	1902
Red pine	1,058,717	1913
Pitch pine	1,638,706	1911

Continuous.

383. Introduction of exotic forest trees. To experiment with exotic species in order to ascertain their growth and yield, and to increase our knowledge of their silvical characteristics.

Work conducted in all parts of the State. The species which have been planted are listed in the following tabulation, which gives the total number set out and the year when the first plantation of each species was established:

Species.	Number Planted.	Year of Earliest Planting.
Norway spruce	4,915,563	1908
Scotch pine	2,971,909	1909
European larch	712,592	1909
Douglas fir	104,566	1914
Western white pine	33,688	1913
Japanese larch	32,500	1917
Western yellow pine	21,985	1908

in addition to the foregoing the following have been set out in small quantities: white spruce, Riga Scotch pine, Finnish Scotch pine, Siberian larch, Chinese arborvitae, Japanese red pine, Japanese black pine, and Himalayan white pine. Twenty-five additional species were planted in spring of 1919.

Continuing.

384. Spacing of seedlings and transplants. To determine the best spacing distance for each species in terms of the locality and the existing vegetation.

Plantations have been established in which the spacing ranges from 3 x 3 feet to 12 x 12 feet. The oldest was established in 1902. Conclusive results will be available in a few years. Work conducted on representative State forests.

To study the established plantation, report their results, and lay out additional plots if necessary.

385. Forest tree planting methods and technique. To ascertain the best and most economical method of planting on specified sites; to make a comparative study of planting tools; to decide upon the most efficient method of organizing planting crews; to determine the cost of planting.

Begun in 1899. Large amounts of reliable data have been collected. General reports have been published. Work conducted on all State forests.

Continuous.

386. **Fall versus spring planting.** To determine the advantages and disadvantages of fall planting of forest trees.

Begun in 1907. Continued intermittently since then. Comprehensive study laid out in fall of 1918, when six different species (1,000 seedlings each) were planted on six different forests, on five different planting dates at intervals of two weeks. This experiment comprises 24 separate plantations, covers 67.1 acres, has required 141,235 trees, and cost $1,090.37.

387. **Classification of seedlings and transplants.** To determine a satisfactory method of classifying nursery stock prior to shipment, using age, size, weight, volume, and stockiness as determining factors.

In progress for several years, but more intensively studied during spring of 1919. Work conducted at Asaph, Clearfield, Greenwood, and Mont Alto nurseries.

388. **Age of planting stock.** To determine the age at which small forest tree seedlings may be set out satisfactorily on various planting sites.

During the past ten years numerous experiments have been established using 1, 2, 3, and 4-year seedlings. Work conducted on nearly all of the State forests.

389. **Seedlings versus transplants.** To determine the comparative advantages of seedlings and transplants on specific planting sites.

Experimental plots have been laid out on about 25 state forests beginning with 1902.

Nursery Practice

390. **Nursery fertilizer experiment.** To determine satisfactory kinds and combinations of commercial fertilizers and the proper time to use them in forest tree nurseries.

Begun in 1907. Experiments laid out on a large scale in spring of 1913. Results recorded in 1914–15 report of Pennsylvania Department of Forestry. Additional applications of fertilizer in spring of 1919. Work conducted at Mont Alto, Greenwood, and Asaph nurseries.

To make a more intensive study of the kinds which heretofore gave favorable results.

391. **Winter storage of nursery stock.** To determine satisfactory methods of storing nursery stock out-of-doors, and in storage buildings and cellars.

Experiments with out-of-door methods have been in progress for several years in four of the large State nurseries.

Construction of storage buildings to hold about one million trees.

Silvicultural Systems

392. **Forest conversion methods.** To make a comparative study of the different methods of converting inferior hardwood stands into coniferous stands of fine quality.

Many experimental plots have been established on representative and scattered State forests throughout the State covering the method of treating planting sites before the planting operations, and the methods used after the planting is completed. The investigation covers the intentional burning and plowing of planting sites, and the clear-cutting, partial cutting, and girdling of existing hardwood growth. Cuttings

may be basal, waist high, or top-lopping. Preliminary report published.

To be continued.

Forest Protection

393. **Forest fire fighting equipment and technique.** To determine the best methods and the most satisfactory equipment to use in extinguishing forest fires in different parts of the State.

Many different tools have been devised and numerous methods of extinction employed. Preliminary reports thereon have been published.

To be continued. Progress reports will be issued.

394. **Assessment of fire damage.** To determine a satisfactory and correct method of assessing damage done by forest fires in immature and mature stands. Special consideration given to damage of soil, humus, regeneration, and the loss of increment.

Plan for field work fully outlined.

395. **Forest fire hazard survey.** To prepare a map of Pennsylvania showing the location of all forest areas, particularly those needing immediate and constant protection. Map will serve as a basis for locating forest fire wardens and patrolmen, and for plans to eliminate hazards.

Field work has been in progress since 1915.

Project to be continued and reported on by counties.

Forest Mensuration and Forest Organization

396. **Subdivision of forests into working units.** To ascertain the best and most practical methods of subdividing forests into working and treatment units.

Begun in 1913. Work interrupted during the war. Subdivision work on one forest completed. Work conducted on Barree, Nittany, Mont Alto, and other State forests.

Work will be resumed in 1919.

397. **Permanent sample plots.** To make an intensive study of carefully selected plots in order to determine the quantitative and qualitative growth of stands, the interrelation of various forms of vegetation, and the correlation of soil and species, to ascertain data for the preparation of stand, age-class, site-quality, and growing stock maps.

Large number of plots have been established. Additional ones are established annually.

Continuous.

398. **Growth studies.** To ascertain the juvenile growth and development of all the native and introduced species occurring in pure and mixed plantations.

Several hundred permanently demarcated plots have been established and the growth existing thereon recorded on special forms. Work conducted on each of the 52 State forests.

Continuous.

399. **Growth acceleration by subsoil dynamiting.** To determine the effect of sub-soil dynamiting on the growth of different species of forest trees in plantations.

Treated areas of one acre each and an accompanying check area laid

out between September 27, 1911, and October 14, 1911, on each of the following State forests, Mont Alto, Grays Run, Stone, Wetham, Stuart and Minisink.

Forest Utilization

400. **Stave production.** To determine an economical method of manufacturing staves from blighted chestnut trees, and to ascertain the yield of staves per unit of volume and per acre.

Operation in progress since 1918 on Buchanan State Forest. Preliminary report ready.

To be continued on Buchanan Forest and extended to other forests.

PENNSYLVANIA STATE FOREST ACADEMY

E. A. Ziegler, Director, Mont Alto, Pa.

(Forest investigations on the Mont Alto State Forest and Nursery; now under the general control and coordination of the Division of Silviculture and Investigation, Department of Forestry, Harrisburg.)

Silviculture and Silvics

401. **Permanent sample plots.** To obtain accurate quantitative and qualitative data on growth and yield of mixed hardwood and coniferous stands; to determine site quality on basis of productive capacity, and subordinate vegetation serving as site indicators.

Established annually from 1912 to 1916, Mont Alto State Forest.

Continuous. Measurement each five years. Pure chestnut and mixed chestnut and oak plots injured by chestnut blight to be continued as a study of species naturally replacing chestnut.

402. **Method of establishing sample plots.** To determine an accurate and economical method of locating representative areas suitable for sample plot purposes.

Mont Alto State Forest field work completed. Report in preparation.

403. **Effect of different grades of thinnings.** To determine influence of light, medium, and heavy thinnings upon the remaining trees and to ascertain the consequent stimulation of the growth on the forest floor. Thinnings repeated at various intervals and applied to different aged material.

In progress since 1905. Additional areas treated annually. Control on many plots containing chestnut destroyed by advent of chestnut blight.

Continuous.

404. **Growth study.** To secure reliable data concerning the growth of some important timber trees by means of accurate tree analyses.

Begun in an intensive and systematic form in 1915 on the Mont Alto State Forest. Species studied: White pine, hemlock, pitch pine, table mountain pine, Jersey or scrub pine, chestnut, white oak, rock oak, scarlet oak, black birch, and tulip tree.

Continuous.

405. **Forest conversion methods.** To ascertain a method of converting the hardwood sprout forests into coniferous high forests, which is silviculturally satisfactory and economically recommendable.

In progress since 1910 on the Mont Alto State Forest. Numerous experimental plantings have been made and considerable acreage has been variously treated. Some preliminary results published.

406. Growth studies. To ascertain the juvenile growth of some of the most important timber trees in pure and mixed plantations.

In progress since 1913, covering numerous plantations established since 1902. Species studied: White pine, western yellow pine, Scotch pine, Norway spruce, European larch, white ash, eastern catalpa, white oak, rock oak, chestnut, black walnut.

Continuous.

407. Phenological growth studies. To determine the factors of growth and their relative influence. To ascertain *when* the important timber trees begin growth in spring, *when* their growth ceases, and how it progresses during the active period. Study of the periodicity of growth. Application of results to nursery practice, forest planting, improvement cuttings, and lumbering operations.

Begun in 1917 on the Mont Alto State Forest. Daily measurement of selected trees during the grand period of growth. Preliminary report in preparation.

408. Tree distribution. An intensive survey of the occurrence of the native trees of Franklin County, Pennsylvania. Also a systematic correlation of the natural occurrence of the different species and the habitat.

Begun in 1915. Field work almost completed.

Nursery Investigations

409. Experimental nursery practice with exotic and native species. To ascertain the best methods of handling species in the nursery.

Experiments are now under way with the following exotic and native species:

Species.	Experimental work begun.	Probable date of results.
Pinus montana (European Mtn. pine)	1916	1921
P. densiflora (Japanese red pine)	1916	1921
P. thunbergii (Japanese black pine)	1916	1921
P. koreensis (Korean pine)	1918	1922
P. edulis (western pinyon pine)	1918	1922
P. ponderosa (western yellow pine)	1917	1921
Juniperus virginiana (eastern red cedar)	1917	1922
Celtis occidentalis (hackberry)	1917	1922
Liriodendron tulipifera (tulip poplar)	1917	1922
Liquidambar styraciflua (red or sweet gum)	1917	1922
Diospyros virginiana (persimmon)	1917	1922

It is planned to begin this spring experimental work, as above outlined, with the below listed species, each of which should be under observation in the nursery for about five years:

Cryptomeria japonica—Japanese cedar.
Gingko biloba—Chinese gingko.
Cedrus libani—Cedar of Lebanon.
Picea sitchensis—Sitka spruce or tide-land spruce.
Pseudotsuga taxifolia—Douglas fir (both green and gray forms).
Picea engelmanni—Engelmann spruce.

Abies concolor—Western balsam or white fir.

There are also under observation in the nursery arboretum the following exotic species, most of which were received from the Bureau of Plant Industry, U. S. Department of Agriculture:

Pinus excelsa—Himalayan white pine.
P. pentaphylla—Five leaf pine.
P. pyrenaica—Pyrenean pine.
Abies nordmanni—Nordmann's fir.
Salix babylonica—Chinese form.
S. vitellina—Russian golden willow.
S. viminalis—from Madeira Isles—Mountain osier.
Four (4) *Salix* species introduced from China and Russia.
Populus balsamifera, var. Wobstii—Russian balsam poplar.
P. sauvolens—A mountain poplar of China.
P. laurifolia—White barked poplar.
P. simonii var fastigata—Chinese small-leaved poplar.
P. sinensis—Crimean poplar.
P. brevifolia—Chinese short leaf poplar.
Five (5) *Populus* species from China and South Europe.
Ulmus pumila—Hardy Chinese elm.
U. parvifolia—Chinese small-leaf elm.
Acer truncatum—A Chinese maple.
A. buergeranium.
Juglans—Species from China.
Liquidambar formosana—Chinese sweet gum.
Castanea pumila X crenata—Hybrid of American chinkapin and Japanese chestnut (resistant to blight).
Juniperus chinensis—Chinese juniper.

It is proposed to distribute stock of these species among State forests in different sections of the State, so as to get information upon their frost-hardiness, soil and moisture requirements, possibilities in connection with extending their range in Pennsylvania, general forestal and ornamental significance, etc. To get definite results of real value along these lines will take five years or more in practically every case.

Seedling exposure experiments with various species and under differing weather conditions should be resumed again in the nursery as soon as the time becomes available, and student investigations resume their pre-war status.

410. Experimental nursery practice with exotic and native species. The use of charcoal braize as a soil amendment to bring the stiff clay soil to favorable physical condition has probably passed the experimental stage in the Mont Alto Nursery; yet some studies are still advisable to determine the optimum application. Norway spruce begins to suffer already in some parts of the nursery where charcoal has been most heavily used, showing that the soil is too dark and warm for this species.

Utilization and Mensuration

411. Portable mill scale study. To compare the actual mill cut with the different methods of scaling; to ascertain the mill factor of different species; to determine the proportion of the different grades of products and the percentage of waste; to build up local volume tables for subsequent use in timber estimating.

Work conducted on Caledonia and Mont Alto State Forests. Species studied: White pine, pitch pine, hemlock, red oak, scarlet oak, and chestnut.

Continuation of study and extension to other important species.

412. **Lath production.** To ascertain the quantity and quality of lath obtainable from the slabwood produced by a portable sawmill per thousand board feet of lumber and per cord of slabwood.

Work conducted on Mont Alto State Forest. Species studied: White pine, pitch pine, chestnut, and hemlock.

To be continued. About one-fourth complete.

413. **Production and yield of chestnut shingles.** To ascertain the most economical method of producing chestnut shingles; to determine the yield of shingles per cubic foot and cord; to prepare a yield table giving the number of standard shingles per tree classified according to diameter breast high and used length.

Mont Alto State Forest. Field work completed. Report being prepared.

Management and Organization

414. **Subdivision of forest into working units.** The subdivision of forest properties into units of working (compartments) and units of treatment (lots). In progress since 1913 on the Mont Alto State Forest. Will be continued until entire forest of 22,000 acres has been organized on a continuous yield basis.

415. **Stand differentiation.** To segregate the stands of a forest for the purpose of making a stand map which will serve as a basis for stand descriptions, formation of lots, a complete stock survey, and yield computation.

Has been in progress on a small scale since 1916, Mont Alto State Forest.

Will be continued until all the stands on the forest have been differentiated.

Pathology

416. **Forest tree disease survey.** Preparation of check-list of all forest tree diseases in the vicinity of Mont Alto.

Begun in 1913. Preliminary list complete.

To be continued.

NEW JERSEY

STATE OF NEW JERSEY

Department of Conservation and Development, Division of Forestry, Alfred Gaskill, State Forester, Trenton, N. J.

C. P. Wilber, State Firewarden, Trenton, N. J.

(Assignment: Projects on State Forests are conducted by Forest Rangers or Assistant Foresters under supervision of the State Forester. Other projects are conducted by Assistant Foresters under supervision of the State Forester.)

Silvicultural Management

417. **Forest planting.** To determine the most practical species for planting on the various types of soils and exposures and the practicability of planting as forest enterprise.

Forest planting was begun in 1907 and has continued up to the present: (*a*) on State Forest land, chiefly for experimental and demonstration purposes; to date approximately 50 acres have been planted; and (*b*) cooperatively on properties of private and public individuals and organizations, chiefly as commercial enterprise, although also having experimental and demonstration value; to date over 1,600 acres have been planted.

Plantations will be extended, both on State Forests and on private and quasi-public lands, according to the policy above outlined. (Forest planting is unnecessary on most of New Jersey forest land because natural reproduction is usually adequate, and is recommended only on non-arable lands unwisely cleared for agriculture, or where fire has killed all reproduction. Furthermore, planting is not justified until protection is assured.)

Intermediate Cuttings

418. **Cleanings.** To determine the species which may be left to best advantage and the effect of the cleaning on subsequent growth.

Very little done yet except incidentally in connection with other sorts of cuttings.

Work will be commenced during 1920 on State Forests.

419. **Thinnings.** To determine and demonstrate increased growth and enhanced quality in thinned stands.

Thinnings were made on State Forests from 1908 to 1912 and subsequently records have been kept of results. Since 1907 thinnings have been made on private lands by individuals and organizations cooperating with the State Forester. Records have been kept in many cases.

Work will be continued and extended both on State Forest and lands of cooperators. Records will be kept.

420. **Improvement cuttings.** To demonstrate the value of proper cutting of woodlands.

Improvement cuttings have been made on State Forests and on privately owned lands, especially where work has demonstration value.

This work will be continued and extended, both on State Forests and cooperatively on private lands.

Growth Studies

421. **Quality and volume growth.** To determine quality and volume growth of timber in natural, thinned, improved, planted and burned-over (periodically and intermittently) and unburned stands; the growth of individuals and of stands.

Some data collected intermittently since 1907, but in 1919 a definite program was initiated for collecting such data on State Forests, and elsewhere when practicable.

Work will be continued and extended as opportunity offers, both on State Forests and on private land where cooperation is being carried on.

Protection

422. **Effect of systematic burning.** To determine the effect of absolute protection as compared with controlled periodic burning, controlled annual burning, and uncontrolled intermittent burning, on the growth and quality of species, stands and soils.

Not yet started.

Work will be commenced on State Forests in South Jersey during 1920.

Special Investigations

423. Tree diseases and insects. To determine the extent and importance of injury, its causes and control.

Sporadic unrelated investigations as conditions demand or permit in cooperation with State Entomologist and State Pathologist.

This cooperative arrangement, and the policy of watchfulness will be continued.

424. Land clearing. To determine methods of killing trees or stumps on land to be cleared to prevent sprouting, and to permit of easier removal.

Sample plots of growing trees, recently cut-over land, and young sprout growth were selected on State Forests, State Experiment Station and on private lands; and treated with various amounts of salt, sulphur, and arsenic solution. Commenced in 1919, cooperating with State Experiment Station.

Data will be collected from the work commenced, and if practicable, further experiments will be continued and extended.

425. Utilization. To determine new and better uses for native and planted species.

Not much has been done as yet, except upon occasional requests for assistance from cooperators.

Work will be continued and extended in connection with market studies and cooperation. Wood users will be encouraged to test out new species.

MARYLAND

MARYLAND STATE BOARD OF FORESTRY

F. W. Besley, State Forester, Baltimore, Md.

426. Utilization of Maryland trees. Field study of the important species, particularly loblolly pine, in relation to their various uses.

Last summer about 100 sample plots were measured for yield tables, in various even aged, fully-stocked stands of loblolly pine, and several hundred taper measurements were made.

Taper curves to be prepared, resulting in volume tables of different kinds. Logging and mill studies to be conducted both in pine and hardwood to determine costs of various products from the tree to the manufactured state.

427. Use of loblolly pine for mine props.

Different-sized sticks weighed by means of a large crane-scale, to correlate DBH and height with weight. This investigation is important in southeastern Maryland, where props are sold in large sticks by the ton.

428. Deadening. To determine the most effective means of deadening trees.

Experiments conducted with different species and sizes of trees, using ordinary methods of girdling, a blow torch, and poisons.

429. **Forest taxation.** To collect data as a basis for revising the Maryland tax laws relating to woodland.

Investigation of the present methods of taxing woodlands in the various counties of the State and the effect upon timber production.

430. **Natural regeneration of loblolly pine.** To determine best method of securing natural regeneration of loblolly pine after logging.

Plots have been established where the seed bed was prepared by burning after logging off all but selected seed trees.

On selected plots, seed bed to be prepared with spring tooth cultivator prior to logging.

431. **Removal of litter.** To determine effect of removal of pine needles from forest floor, upon growth of loblolly pine.

Plots have been established in stands where soil cover has been undisturbed. From certain of these the pine needles will be removed at regular intervals.

Periodic measurements to be made in the undisturbed plots, as also in the plots where pine needle cover has been removed.

SOUTH ATLANTIC STATES

NORTH CAROLINA

NORTH CAROLINA GEOLOGICAL AND ECONOMIC SURVEY

J. S. Holmes, State Forester, Chapel Hill, N. C.

432. **Regeneration of cut-over longleaf pine areas in the Sandhills region of North Carolina.** To show the most practical method of reseeding longleaf and find out whether some other species will not be more satisfactory for reseeding such areas.

Work begun on Sandhills State Forest, Hoke County, in 1916. A number of seed plots sown in that and each succeeding year. Longleaf, loblolly, shortleaf, slash, and maritime pines are being tried. A number of seed beds were started in the spring of 1919, some under lath covers and some in the open. Mice and other vermin have destroyed practically all of these seedings.

Observations on present plots will be made from time to time and any promising results carefully noted and possibly published. Further seedings will be made, and it is hoped later that plantings can be undertaken.

Experiments on Sandhills State Forest are under direct charge of State Forester, who visits the area several times a year.

433. **Artificial regeneration of cut-over and burned-over spruce type in the high mountains of North Carolina.** To determine the best species and the most effective methods of seeding and planting.

Work begun on Mt. Mitchell State Park (elevation over 6,000 feet) spring of 1918. A number of seed plots sown in different locations with seed of red spruce, Norway spruce, hemlock, and locally collected Fraser fir. A small experimental nursery has also been started.

Examinations will be made of present plots and seedings made of other species, especially white pine. Plantings will be made from time to time of promising species, and also Fraser fir and spruce coming up naturally in the uncut forests.

Seed plot experiments on Mt. Mitchell State Park have been conducted by D. L. Moser, Black Mountain, N. C., who is in charge of the Park and resides upon it. State Forester directs and supervises work.

NORTH CENTRAL STATES

OHIO

OHIO AGRICULTURAL EXPERIMENT STATION

Department of Forestry, Edmund Secrest, Chief, Wooster, Ohio

Silviculture

434. **Soil fertility experiments in the propagation of forest planting stock.** To determine the kinds, quantities, and combinations of different fertilizers for production of nursery stock.

Work begun in 1916 in white pine seed beds. Continued on white ash, white pine, and catalpa in 1918.

These experiments will be extended to other species.

435. **Forest arboretums.** To determine adaptation of species to different soil conditions, to determine species adapted for mixtures in plantations, spacing distances, and degree and frequency of thinnings.

Work begun 1906 with native and exotic species. Successive plantations have been established each year.

To be continued as conditions warrant.

436. **Tree studies.** Studies of commercial tree species with reference to silvical characteristics and utilization.

Field work on the white ash completed and data have been compiled. Partial data on white, black, red, scarlet, and chestnut oak secured.

Studies to be extended to other species.

437. **Natural regeneration studies.** Extent of woodland grazing and effects upon reproduction. Influences affecting the composition of the reproduction on different forest types.

Begun in 1908.

To be continued.

438. **Forest survey.** Detailed surveys by counties.

Begun in 1907. Bulletin No. 204- No. 211, Ohio Experiment Station.

To be continued.

Forest Products

439. **Timber markets and marketing conditions in Ohio.** Distribution of commercial timber by species.

Begun 1916. Preliminary report. Bulletin 302, Ohio Experiment Station. Report in press.

To be continued.

440. **Durability of farm timbers.**

Bulletin No. 219 and Monthly-Bulletin for March, 1919, Ohio Experiment Station.

To be continued.

INDIANA

STATE BOARD OF FORESTRY

Chas. C. Deam, State Forester, Indianapolis, Ind.

441. **Trees and shrubs of Indiana.** To be published as a book, illustrated.

About one-third written.

To be completed in two years.

442. Investigation of the growing of black locust in Indiana.
A continuing project.

443. Studies of growth rate.

PURDUE UNIVERSITY

School of Science, Stanley Coulter, Dean, Lafayette, Ind.

444. Rate of growth of commercial hardwoods under varying ecological conditions.

The areas selected for investigation are forest tracts in which cutting is being done. The ecological factors of the areas are studied intensively. Sections from the trunks of the trees felled are sent to the Laboratory for careful study. The work has been under way for several years.

Assigned to Prof. Coulter, assisted this year in the collection of material by the State Conservation Commission.

445. Natural afforestation of barren lands. To ascertain the factors responsible for the afforestation of an originally barren area in Clark County, Indiana.

This area was fairly well delimited in 1845–50 by Dr. A. M. Clapp, of New Albany. It was originally treeless but surrounded by forests At present the "Barrens" are represented by a heavy young growth of hardwood species.

Under the direction of Prof. Coulter.

ILLINOIS

STATE NATURAL HISTORY SURVEY DIVISION

Stephen A. Forbes, Chief, Urbana, Ill.
R. B. Miller, State Forester, Urbana, Ill.

446. Correlation between different forest types and different types of soil.

The work of correlation is now going on in seven counties. It is based on the admirably exact and detailed work of the Soil Survey of the State, which has been in active operation for the last 17 years.

Reports or partial reports on the seven counties will be published soon in the annual report of the Illinois Academy of Science and later, perhaps, as bulletins of the Natural History Survey.

Assigned to a corps of volunteer workers in cooperation with the State Forester.

447. Forest survey of a county in southern Illinois, probably Union County.

New project.
To be conducted in summer of 1920.

GULF STATES

GEORGIA

COOPERATIVE EXTENSION WORK

Louis A. Zimm, Extension Forester, Athens, Ga.

448. Thinning.
Two projects under way, on which work will probably be done this fall.
Assigned to L. A. Zimm.

449. Coal-tar treatment of sap pine posts.

Six fence post, demonstrations to determine the value of sap pine posts treated with coal tar.

Assigned to L. A. Zimm.

450. Marketing of farm woodland products.

It is proposed to have several demonstrations started by fall.

Assigned to L. A. Zimm.

ALABAMA

GEOLOGICAL SURVEY OF ALABAMA

Roland M. Harper, Botanist, University, Ala.

451. Investigation of all natural resources, including trees and wild plants.

Botanical studies by Dr. Charles Mohr were conducted in the last quarter of the 19th century, culminating in "Plant Life of Alabama," published in 1901. From about 1896 to 1901 some botanical field work was done around Auburn by Prof. F. S. Earle and associates. In 1908 J. H. Foster of the U. S. Forest Service made a reconnaissance of the forests in cooperation with the State, and submitted a manuscript report which has not been published. R. M. Harper began work in Alabama in 1905 as Botanist of the Geological Survey, and has spent about three years, intermittently, visiting every county in the State. Preliminary results in botanical magazines beginning 1906. Part 1 of "Economic Botany of Alabama," a geographical report on forests, was published in 1913 as Monograph 8 of the Survey; abstract appeared in American Forestry, same summer. Supplementary paper entitled "A Forest Census of Alabama by Geographical Divisions," by R. M. Harper, in Proc. Soc. American Foresters, April, 1916, Vol. 11, No. 2, 208–14.

The forests are being studied from the regional and quantitative point of view; *i. e.*, the State is first divided into natural regions, and then the relative abundance and stand of each species estimated. The second part of the Economic Botany, a catalog of the trees and shrubs with their distribution and uses, is well advanced and will be published at the first opportunity.

Assigned to R. M. Harper.

LOUISIANA

DEPARTMENT OF CONSERVATION

R. D. Forbes, Superintendent of Forestry, New Orleans, La.

Forest economics

452. A study of the comparative costs of logging large and small timber as a basis for recommending a diameter limit in logging and thereby securing a measure of forestry practice among the lumber companies.

A preliminary report on this project was made in November, 1919. The data obtained up to that date were significant but not conclusive.

Further data will be collected from time to time.

Under direction of R. D. Forbes.

Silviculture

453. Growth rate of second-growth longleaf pine: to afford yield data as a basis for predicting returns from the practice of forestry.

Plans prepared; proposed to begin field work about July 1, 1920, and to continue it intermittently throughout the year.

Assigned to one or two field men under direction of R. D. Forbes.

454. **Slash pine in the prairie region of southwest Louisiana:** its adaptability, rate of growth, and qualifications as a farm woodland tree.

Two acres of prairie land were seeded on May 1, 1919, to slash pine, one acre broadcasted, and the other seed-spotted with spacings of 6 x 6 and 8 x 8 feet. Seed provided by the U. S. Forest Service.

Plans for future work include simply observations of the results of the planting.

Under direction of R. D. Forbes.

LAKE STATES

MICHIGAN

STATE OF MICHIGAN

Public Domain Commission

Marcus Schaaf, State Forester, Grayling, Mich.

455. **Underplanting.** To determine the success of underplanting in summer and early fall.

Experimental planting is being conducted to determine the success of underplanting during the summer and early fall months. Commencing the first of June and continuing until October, one-half acre is planted each week to 3-0 white pine, 875 per half acre. Planting done in some manner as in spring and fall planting.

456. **Silvical study of Norway and white pines.**

A silvical study of a virgin, even-aged, well stocked stand of Norway and white pine covering 200 acres is being made.

Will be completed in 1919.

457. **Silvical study of jack pine.**

Begun 1919. Study will seek to determine: (*a*) into what site classes jack pine land may be most conveniently divided for the State work, and description of sites for ready recognition; (*b*) rate and habits of growth when pure and when in mixture with other pines and hardwoods; (*c*) number of trees per acre at different ages for optimum growth and thrift; (*d*) the serious injuries to which the species is subjected, and methods of control.

Will be continued for several years.

MICHIGAN AGRICULTURAL COLLEGE

Department of Forestry

A. K. Chittenden, Professor of Forestry, East Lansing, Mich.

458. **Sand dune and drift control.**

(*a*) Drift control: demonstration plantings.

Three demonstration plantings established: (1) Holland Drain Project: Sand blow to be held by forest planting; begun 1916, 4 miles north of Holland. (2) Loss Farm, Muskegon: 20-acre tract moved by wind in 10 years; work begun 1918. (3) Big Prairie: control attempted by Mr. Barton and State; work begun 1918. Forest tree stock supplied by college nursery was planted on all three projects in spring of 1919. Each under direct and personal control of County Agricultural Agents

of respective counties. Planting supervised by Field Agent E. C. Mandenberg.

These areas to be kept under observation and data to be secured. Repair planting to hold control of drift sand will be made whenever necessary. Final development into county forests and experimental parks.

Michigan Experiment Station foresters to be in charge of collection of data and plans for future handling as experiment. To cooperate fully with County Agents and owners.

(*b*) Sand dune control and reforestation.

Work not yet started. Plantings planned in three localities: (1) Ocean County, on bad traveling dunes; examination made and plans considered. (2) At Saugatuck: complete plans and specifications have been prepared. (3) Berrien County; plans now being prepared by County Agent Lurkins.

Work on large scale is necessary; to be financed by owner; plans and supervision to be furnished by Station, labor and planting material by owner. It is hoped that a plan of cooperation may be affected, whereby one or more of the larger dune areas may be used for demonstration.

Foresters only to be assigned to cooperation experimental project in reforestation. Cooperation triangular: Owner-Co. Agt. Michigan Experiment Station.

459. Fall planting.

A careful test run over a five-year period to determine safety of fall planting, kinds of soil, species, and ages best adapted for Michigan.

Use records that are available and accurate, of plantings already established. Establish new plantings. Full data to be filed on: (1) location, (2) soil, (3) exposure, (4) species and age, (5) method of planting, (6) subsequent care.

Assigned to forest students under supervision of forester.

460. Diameter, height, and volume growth of forest plantations: determination for various species planted in Michigan during past 50 years.

Measurements made of (*a*) plantations and second-growth forests and (*b*) highway and shade trees, with reference to influence of spacing, pruning, soil, exposure, and care. Work to be done in all parts of the State in order to be representative of the State as a whole. Field work completed.

Assigned to Forester and student assistants.

461. Availability of ironwood for ax helves in Michigan, with possible inclusion of sassafras, dogwood, juneberry, etc.

Study is aimed to tell whether there will be a future, and the localities involved.

Careful estimates to determine feasibility of utilizing ironwood, to be made in representative areas in each county in a district.

462. Utilization of minor species for special purposes, with particular reference to seasoning.

It is proposed to determine the best uses for little-used species which grow as understory trees: ironwood, dogwood, blue beech, sassafras, juneberry. Special studies in kiln work and in close technical tests.

Work to be done at the college; to include methods of air and water

seasoning, as well as kiln work. Records to be kept and results published. If supply warrants, effort to be made to bring about utilization of species suited.

463. **Maple sirup study.** Study of flow of sap as influenced by number of tapholes; fuel costs, etc.
Begun in 1916. Partial results published from time to time.

UNIVERSITY OF MICHIGAN

Department of Forestry, Filibert Roth, Professor of Forestry, Ann Arbor, Mich.

464. **Planting.** Methods and spacing.
The species and date of starting are as follows:
Scotch pine—1904, '06.
Austrian pine—1904, '06.
White pine—1904, '07, '15.
Douglas fir—1904.
Yellow poplar—1904.
Catalpa—1904, '15.
Norway spruce—1904, '11, '15.
Black locust—1904, '06.
White ash—1906, '08, '19.
Red oak—1906, '07, '08, '15.
White oak—1906.
Black walnut—1906, '09.
Hickory—1906.
Osage orange—1905.
Western yellow pine—1906, '08, '09, '12, '15.
Russian mulberry—1906.
Box elder—1906.
Basswood—1906.
White elm—1906.
Sugar maple—1906.
Chestnut—1907.
Cottonwood—1912.
Norway pine—1919.
In charge of forestry faculty, with student assistance.

465. **Thinning.**
The dates of thinning are as follows:
Black locust—1914.
Scotch pine—1915, '19.
White pine—1915.
Austrian pine—1919.
Western yellow pine—1919.
White elm—1918.
White ash—1919.
All thinnings are repeated at five-year intervals.
In charge of forestry faculty, with student assistance.

466. **Coppice reproduction.**
Catalpa—1911, '15.
In charge of forestry faculty with student assistance.

467. **Selection cutting.**
Mixed hardwoods—1917, '18, '19.

These cuttings are repeated on each compartment every ten years, the results upon growth and reproduction being studied by permanent sample plots.

In charge of forestry faculty, with student assistance.

468. Growth study.

Conducted by measurements of all plantations at five-year intervals, treating each one as a permanent sample plot.

In charge of forestry faculty, with student assistance.

MINNESOTA

UNIVERSITY OF MINNESOTA

Division of Forestry, E. G. Cheyney, Director, Univ. Farm, St. Paul, Minn.

Experiment Station, W. H. Kenety, Cloquet, Minn.

Sowing and Planting

469. Tests of species.

The tests of species from other parts of this country and from the Bureau of Foreign Seed and Plant Introduction have been continued. Several promise to have special merit for Minnesota, one species of poplar from Russia showing exceptional promise.

Assigned to W. H. Kenety.

470. Comparison of different classes of stock.

Now includes over 400 half-acre plots. Last year 20 half-acre plots were planted with jack pine and Scotch pine, which completed the planting in this experiment with different classes of stock in different situations. Counts and measurements of about 200 one-acre plots were made when the fires occurred.

Counts and measurements will have to be made for many years to come. Field plots to be laid out on the State forests in the northeastern part of the State to determine best methods and stock for reforestation of the types of land found in the new State forests.

Assigned to W. H. Kenety.

471. Seasons for sowing and planting.

Work practically completed. Results relating to nursery work have been written up and included in the report of the Station.

Work will have to be continued to secure average results over a number of years.

Assigned to W. H. Kenety.

472. Effects of cover under planting.

Experiments now include about 150 plots. Work on effects of cover and stock best suited to replace jack pine finished as far as planting is concerned.

Plots to be measured yearly.

Assigned to W. H. Kenety.

473. Study of site factors.

In 1918, three years' work had been completed at the Station. The moisture equivalent determinations for white spruce are fairly complete. Data have been secured for most of the commercial species, though they are far from complete.

Assigned to W. H. Kenety.

Nursery Practice

474. Methods and factors.

The work has been completed in part and results published in the report of the Station. Work on fertilizing, spacing, and damping off not completed. In 1918 nursery studies were continued for white spruce, but no satisfactory methods have as yet been found to make success certain with this species.

Intensive experiments in progress on fertilizers for seed beds and transplant beds.

Assigned to W. H. Kenety.

475. Damping-off of coniferous seedlings.

Work continued in 1918 on white spruce, but results are not satisfactory. The results of the work previously done are now compiled and with the completion of this year's work will be ready for publication. Very intensive experiments are under way to complete the work this year. This will mean the planting and counting of 70 beds and will take the full time of three men.

It is expected to finish this work this year.

Assigned to W. H. Kenety and E. M. Freeman.

Seed Studies

476. Collection, treatment and characteristics of forest tree seeds.

Work on seed collection, extraction, and cleaning was conducted in 1918 for balsam fir and white cedar. Work completed for white spruce and Norway pine, fairly complete for white pine and jack pine. Some results have been secured on source of seed in relation to hardiness and immunity to insect and disease attacks.

Assigned to W. H. Kenety.

Management

477. Natural reproduction from seed trees.

Plots have been laid out in areas where seed trees have been left and where cutting was made during and immediately after a good seed year.

Plots to be recounted this year.

Assigned to W. H. Kenety.

478. Effects of thinnings.

Thinnings and check plots have been made in three different densities and ages of jack pine, and Norway pine; these were remeasured in 1918 for height and diameter, the cubic contents have been computed, and the increment determined for the 5-year period.

Thinning plots to be remeasured in 1919. Paper on comparative annual increment and mortality in jack pine and Norway pine to be prepared for publication.

Assigned to W. H. Kenety.

479. Brush burning.

No more work has been done except to render a report to the State Forester.

Proposed to study effect of brush burning in relation to reproduction in the different ranger districts if help and funds become available.

Assigned to W. H Kenety.

480. Working plan for Itasca Park.
Preliminary plan prepared.

When the cutting of private holdings is completed, a definite 10-year planting plan should be prepared, as planting will be the most important forest operation within the Park for many years. Record books in the form of maps and tabulations, so made as to be readily kept up to date, should be prepared.

Assigned to J. H. Allison.

Mensuration

481. Mill scale study of white and Norway pines.
A graded mill scale study of 3000 white and Norway pine logs has been made and the computation completed.

Articles on this study to be prepared for publication.

Assigned to W. H. Kenety.

482. Volume growth and yield of commercial species.
Some data have been secured for nearly all the commercial species, but a special detailed study of each species is badly needed and the data will be added to as quickly as help and funds permit.

Assigned to W. H. Kenety.

483. Sample plot study of volume and yield in Itasca Park.
Sample plots have been established in jack pine and aspen stands, measured, and results tabulated. Rate of growth of 23-year old jack pine to the east of Lakes Mary and Itasca found to be approximately 1 cord per acre per year.

Measurement of additional sample plots in other jack pine and aspen stands—possibly in stands of other species also.

Assigned to J. H. Allison.

484. Grand Rapids growth studies.
Sample plots in planted stands of Norway, jack, and Scotch pine at Grand Rapids sub-station, for study of yield.

Plots to be measured in 1920.

Assigned to J. H. Allison.

Windbreaks and Prairie Plantations

485. Windbreaks and prairie plantations. A mass of material was gathered in 1917 on windbreaks in western Minnesota. Notes have been completed and manuscript finished on trees on Minnesota farms.

Publication postponed for a short time to incorporate material recently secured.

W. H. Kenety.

Wood Preservation

486. Preservative treatment of fence posts. To determine best and most economical treatment of fence posts cut from six species common to farms in Minnesota.

Begun 1909, in cooperation with the United States Forest Service. Part of the 3000 variously treated posts were set in the fences and vineyards at the Fruit Farm, Zumbra Heights. The remainder were sold to farmers living near by. The posts have been inspected annually by the Division of Forestry and biennially by the U. S. Forest Service.

Assigned to J. H. Allison.

487. Effect of structure, time of cutting, and methods of seasoning of white cedar, on the penetration of preservatives. To determine the reason of and remedy for the great variation in penetration of preservatives in cedar poles when treated under uniform conditions.

New project.

Material will be cut in the woods at different times of the year, and seasoned in several different ways in the open air. Rate of growth and structural studies and tests as to permeability will be made.

Assigned to J. P. Wentling.

Studies of Minnesota Woods

488. Wood collection.

Collection of authentic samples of all woods of the United States (especially Minnesota) and preparation of museum blocks of all native woods and sets of authentic specimens for forwarding to various institutions in Minnesota was begun in 1918.

Assigned to J. P. Wentling.

489. Structure, technology, uses, and supply of the common woods of the State.

New project.

Supply and uses to be studied in the field, structure and properties at University Farm.

Assigned to J. P. Wentling.

PRAIRIE STATES

IOWA

IOWA STATE COLLEGE

Department of Forestry, G. B. MacDonald, Professor of Forestry, Ames, Iowa.

490. Timber preservation. To determine most effective means of increasing durability of farm timbers; primarily concerned with native fence post woods and posts commonly used in the State of Iowa.

Preliminary work was started about 1905 when a number of experimental fences were set out. Detailed report on these experiments published in August, 1915, in Bulletin No. 158, Iowa Agricultural Experiment Station.

All experimental fence lines are being continued and will be reported on in detail at intervals of five years. It is also the purpose to extend the experiments by using other preservatives than creosote and also a greater variety of woods.

Experiments were started by H. P. Baker in cooperation with U. S. Forest Service; continued by C. A. Scott 1908–10; now in charge of G. B. MacDonald.

491. Forest planting. To test the value of various native and exotic trees on different sites and soils in Iowa.

Small plantations of the following species have been established and experimental data are being collected; hardy catalpa, Carolina poplar, walnut, white pine and other coniferous species. The project also includes some reforestation experiments on sandy lands adjoining the Mississippi River.

It is the purpose of the Experiment Station to establish additional plantations of various species and keep a record of growth.

Experiments started by C. A. Scott 1908–10; G. B. MacDonald now in charge.

492. **Growth and yield of native and planted trees.** To determine the yield of the more important timber trees in Iowa.

Measurements have been taken covering a large number of plantations of cottonwood, walnut, white pine, and European larch.

It is the purpose of the Experiment Station to supplement these measurements. The growth of additional plantations will be determined and also it is expected to have this work extended to cover native stands.

G. B. MacDonald in charge.

493. **Investigations in forest products.** Principally to determine better methods of marketing Iowa woodlot products.

Some investigations along this line were conducted in cooperation with the U. S. Forest Service. These were published in Experiment Station Bulletin No. 142, in August, 1913, "The Wood-Using Industries of Iowa."

This project will be continued as funds permit.

G. B. MacDonald in charge.

494. **Forest management.** This project includes three sub-projects: Management of native woodlands; effect of grazing on woodlots; and regeneration of planted woodlots. It is the purpose of these investigations to determine a system of forest management for the various timber types of Iowa; the effects of grazing, fire, etc., on the woodlands, and a satisfactory method of regenerating native woodlots or shelterbelts which were planted 30 to 50 years ago for protection.

Circular No. 27, "Renewing the Shelterbelt," published by the Agricultural Experiment Station in 1916.

These investigations will be continued as funds permit.

G. B. MacDonald in charge.

ROCKY MOUNTIAN STATES

IDAHO

UNIVERSITY OF IDAHO

School of Forestry, F. G. Miller, Dean, Moscow, Idaho

495. **Experimental tree planting.** To determine the forest trees adapted for planting in Idaho.

Work begun in 1910. Bulletin 105 of the Idaho Agricultural Experiment Station, "Trees, What, Where, When, and How to Plant," by Shattuck and Cook, published in 1918.

Investigation being continued.

496. **Wood oils for ore flotation.** To determine the practicability of extracting oils from commercial woods of Idaho for use in ore flotation.

Yield in gallons per cord and cost per gallon have been determined for six leading species.

Now awaiting results of tests by School of Mines.

Conducted in cooperation with School of Mines.

497. **Utilization of logged-off lands in Idaho.** To determine the location and area of logged-off lands and what portion of them is chiefly valuable for agriculture, forestry or grazing.

Rough survey now under way.
To be followed by more intensive study later.
Conducted in cooperation with Idaho Experiment Station and Forest Service.

498. **Reconnaissance of State timberland at Big Payette Lake.** To introduce regulated cutting and to develop plan for recreational features of the lake front. Area about 14,000 acres.
Work in progress this summer. Regulated cutting now being practiced on present timber sale area, comprising 2500 acres.
Conducted in cooperation with State Board of Land Commissioners.

499. **Reconnaissance of Hayburn Park, area 8000 acres.** To develop cutting plan for timber, also plan for the recreational facilities of the Park.
Preliminary examination made this summer.
To be followed by reconnaissance study next summer.
Conducted in cooperation with the State Department of Public Works.

500. **Quantitative and qualitative forest increment on cut-over lands.** To determine the amount and character of timber produced upon cut-over lands.
Preliminary plans under way.
To be conducted in cooperation with the Forestry Committee of the National Research Council.

501. **Standardization of Silvicultural practice in the various forest regions of the United States.** To determine the best methods of handling timberlands.
Preliminary plans under way.
To be conducted in cooperation with the Forestry Committee of the National Research Council.

502. **Correlation of biological factors with physical, chemical, and structural qualities of timber.**
Preliminary plans under way.
To be conducted in cooperation with the Forestry Committee of the National Research Council.

503. **Toxicity of pyroligneous acid or its fractions.** To determine the possibility of the utilization of the products of destructive distillation of wood for the preserving of wood.
Preliminary work under way.

504. **Studies in the enzymes of the wood-destroying fungi.** To determine what enzymes are present in the various wood-destroying fungi.
Continuation of former work.

505. **Relative durability of commercial Idaho woods.** To determine the resistance of Idaho woods to decay so that more intelligent utilization can be made.
Work well under way.

COLORADO

COLORADO AGRICULTURAL COLLEGE

Department of Forestry, W. J. Morrill, Professor of Forestry, Fort Collins

506. **Fence post preservation.** Preservative treatment of cheap Rocky Mountain fire-killed post timber.

Posts of lodgepole pine and Engelmann spruce given five, and of alpine fir two different treatments, with local water-gas-coal tar creosote, and with crude petroleum. Control posts untreated, for each species. Records of percentage sound and percentage serviceable after six years placement made in 1918. A second lot of posts, all split cedar (*Thuja plicata*), were placed in ground four years ago after two tank open tank method with water-gas-tar creosote treatment; inspected for first time in 1919.

Experiment to be continued during several years or until practically all the posts have failed.

Assigned to W. J. Morrill.

ARIZONA

CARNEGIE INSTITUTION OF WASHINGTON

Department of Botanical Research Desert Laboratory, Tucson, Ariz.

D. T. MacDougal, Director

507. Measurement of variations in volume of growing trees by the use of the dendrograph.

As a part of a plan for a comprehensive study of growth, the measurement of variations in volume of tree trunks has been undertaken. From a consideration of the records of many other plants and of separate organs showing that in addition to the general march of growth there are daily variations in size, it was found advisable to design an instrument which might be attached to a tree trunk and which would make a complete and continuous record of the diameter or of the circumference. Two general plans for this have been under consideration. In one an encircling wire carried plungers which are in contact with the tree and which serve to communicate changes to the wire which is connected with a recorder. Some results were obtained by an instrument of this kind, but it was found more practical to develop a second type of instrument, in which a rigid yoke constructed of bario, invar, or some metal alloy with a low temperature coefficient, was put in place around the trunk and 1, 2, or 3 contact screws were fitted to the yoke on one side of the tree, while on the other side the bearing end of the lever provided an additional contact. Variations in distance representing the diameter or an approximation of it caused movements of the lever, which were transmitted to the pen arm of the recorder. The recording instrument and the yoke are supported in a suitable manner on a base composed of a belt of hinged wooden blocks around the tree.

Specifically it was proposed to ascertain the variations in the bases of trunks, the bole some distance above the ground, and to extend the measurements to the uppermost part of the trunk.

During 1919 these working models, each slightly different from the others in some part of the mechanical design, have been operating as below, all being attached to the base of the trunk at a distance of about 4 feet from the ground.

One at Baltimore has made a record of an American beech (*Fagus grandifolia*) in the grounds of the Johns Hopkins University since April, under the care of Mr. W. F. Gericke. A second instrument has taken a record of a sycamore (*Platanus occidentalis*) in the Missouri Botanical Garden since April, under the care of Dr. H. von Schrenk. A third instrument was put in place on an Arizona ash (*Fraxinus arizonica*)

14 years old on the grounds of Dr. H. W. Fenner at Tucson, early in March. A fourth was taken up into the Santa Catalina Mountains by pack animals and placed on a Chihuahua pine (*Pinus chihuahuana*) at an elevation of 6000 feet about the first of April. This instrument has been visited weekly by Mr. B. R. Bovee and has made a perfect record. A fifth instrument was attached to a live oak (*Quercus agrifolia*) in the grounds of the Coastal Laboratory at Carmel on February 17 and has made a complete record of the variations in the base of the trunk since that time, the growing season being now closed. A sixth instrument was placed on a Monterey pine (*Pinus radiata*) in March and has worked perfectly since that time. The actual increase for the season is practically terminated.

In addition, various recording devices are in operation in taking the diameter and variations in length of the leaders of small trees and the growth of seedlings of the Monterey pine.

The examination of the records brings to light some very important facts which seem to have been unknown or but little known, in the growth of trees.

The plans for further work are as follows: The experience of the present season is being used in working out an improved design of the instrument of which it is proposed to operate about 25 on various selected species during 1920. Assignments or arrangements with co-operators have not yet been completed, although some correspondence and some conferences have been started with regard to the matter.

Some discussion of the general results this season is being embodied in the Annual Report of this Department, which will be printed and distributed shortly after the first of the year, and possibly the matter will be discussed at some of the winter meetings, although no arrangements have yet been made for doing so.

This project is in charge of local observers under the direction of Dr. MacDougal.

PACIFIC COAST STATES

CALIFORNIA

STATE BOARD OF FORESTRY

G. M. Homans, State Forester, Sacramento

508. Shade and ornamental trees in California. To determine suitable trees in different sections of the State for lawns, residential streets, and highways.

Photographs taken of about 250 typical shade and ornamental trees. Characteristics and habits of these trees are being written up for publication.

Additional photographs will be taken to complete list of illustrations needed for publication.

Assigned to California State Board of Forestry.

509. Planting of shade trees on business streets.

Plane trees planted in heart of business section of Sacramento where basements have been excavated to the curb. Described in Sixth Biennial Report of State Board of Forestry. Trees under observation and photographs taken at intervals to show progress.

Stimulation of planting of various species in city streets. Observation in rates of growth and hardiness of trees under existing conditions.
Assigned to California State Board of Forestry.

UNIVERSITY OF CALIFORNIA, COLLEGE OF AGRICULTURE

Division of Forestry, Walter Mulford, Professor of Forestry, Berkeley

Silviculture

510. A study of the development of stands of Bigtree.

Sample plots laid out and trees measured and tagged August, 1915, in stands of bigtree natural reproduction, Whitaker's Forest, Tulare County, California.

To be remeasured at intervals of five years or more.

Assigned to Woodbridge Metcalf.

511. A study of the growth and yield of various species of eucalyptus on different sites in California.

Work begun on some plantations by Forest Service in 1912. Remeasurements made on these and others by W. Metcalf and J. A. Mitchell in 1916. Sample plots now located in groves from Glenn County to San Diego County, California.

Sample plots to be remeasured at about 5-year intervals. Report on work to date being prepared.

Assigned to Woodbridge Metcalf.

512. A study of trees suitable for windbreak planting on various sites in California.

Proposed in 1916. Location of work; portions of Sacramento and San Joaquin valleys, seacoast, and semi-desert areas. To include a general survey of windbreaks in California and their influence on production of various agricultural crops. No work done to date.

Existing windbreaks to be investigated and comparative records made of wind velocity, temperature, and evaporation in shelter of windbreak and on adjacent unprotected areas. Planting plan to be prepared for University Farm, Davis, Calif., to test accuracy of conclusion.

Assigned to Woodbridge Metcalf.

513. Studies in adaptability and rate of growth of trees in the North Sacramento Valley.

Plantations of over 100 species of trees have been set out on the Chico Forestry Station, Butte County, California, beginning in 1889 and continuing at intervals to the present time. Area has been mapped and growth measurements are in progress.

Publication of results as soon as completed. Plantations to be extended to test other species.

Assigned to Woodbridge Metcalf.

514. Studies in adaptability and rate of growth of trees in southern California.

Seventy species of eucalyptus and many other trees have been set out on the Santa Monica Forestry Station, Los Angeles County. Some of these are now 20–30 years old. Measurements are being made as soon

as accurate identification can be made. All records were destroyed by fire in 1904.

Publication of results, extension of plantations using new species.

Assigned to Woodbridge Metcalf.

515. Trees suitable for planting without irrigation in the Berkeley Hills, Alameda County.

Begun 1916. Tests have been made with species from Australia, New Zealand, Africa, Japan, and China. Some have been raised from seed in the Berkeley Nursery but many have been received from the Plant Introduction Gardens.

Expensive methods of planting have given good results with several species. It is proposed to select species which will stand cheaper methosd of handling. Work to be extended in experimental planting area in Strawberry Canyon.

Assigned to Woodbridge Metcalf.

Lumbering Studies

516. Factors affecting the cost of log making and skidding.

Begun during 1916, during which field season several men made time studies of donkey and big-wheel logging in both the redwood region and Sierra pine region. Data were taken on felling, marking, limbing, hand bucking, steam saw bucking, and yarding. Each operation is analyzed into its component parts, each of which is timed repeatedly. A large amount of data is at hand but has not been worked on owing to the absence of Captain Bruce.

To be continued according to working plan. It is necessary to secure a mass of data large enough so that for each gradation of one variable in the several steps in log making the others will show a reasonably constant average.

Assigned to Donald Bruce.

Mensuration

517. Preparation of volume tables for principal California species.

An investigation has been made as to a proper diameter and height basis for volume tables and tentative conclusions reached. A study is in progress of the best technique of volume table preparation. Tables are being made in a number of different ways from the same data and their accuracy compared. This phase of the project will be completed this winter. Work is started on the preparation of a new volume table for white fir using all available field measurements gathered by the United States Forest Service, the United States Bureau of Plant Pathology and the University.

After the completion of these steps it is planned to continue the preparation of a set of volume tables for California species.

Assigned to Donald Bruce.

518. Quantitative and qualitative forest increment on cut over lands.

This project was initiated by Mr. Raphael Zon at the direction of the National Research Council.

Tentative plans of work have been drawn up and collaborators are being secured in each State.

A survey of existing data will first be made and a bibliography or

summary prepared therefrom. An attempt will be made to standardize the technique of growth studies and to work up a first approximation of the total growth on second growth stands.
Assigned to Donald Bruce.

UNIVERSITY OF CALIFORNIA

Prof. W. L. Jepson, Berkeley

519. Studies on the taxonomy of chaparral species in California.
Independent investigation by Prof. Jepson.

Vol. 1. Part 5 OCTOBER, 1920 Number 5

BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

THE QUANTUM THEORY

By Edwin Plimpton Adams
Professor of Physics, Princeton University

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1920

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BULLETIN

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THE QUANTUM THEORY

By Edwin P. Adams

Professor of Physics, Princeton University

CONTENTS

INTRODUCTION

One of Lord Kelvin's last lectures was entitled "19th Century Clouds over the Dynamical Theories of Heat and Light," which he gave at the Royal Institution in the last year of the 19th Century. Lord Kelvin's scientific work was very largely devoted to dynamics. No explanation of any physical phenomenon that was not a dynamical explanation made any appeal to him. For example, the electromagnetic theory of light did not satisfy him; it was no explanation of light phenomena in terms of primary dynamical notions—motion of masses in ordinary space and time according to Newton's laws.

The first of the two clouds to which he referred was the difficulty of explaining by dynamics the fact that the earth moves freely through a medium such as the ether, which can transmit the transverse vibrations which constitute light, in such a way that the motion of the earth has no effect on optical experiments performed on the earth. Lord Kelvin was quite prepared to give up one of our fundamental notions—that two bodies cannot occupy the same space at the same time—but he was unable to account for the

negative results of experiments such as the Michelson-Morley experiment on dynamical grounds. His conclusion, after a discussion of the possibilities was simply, "I am afraid we must still regard cloud No. I as very dense."

Cloud No. II had to do with the doctrine of equipartition of energy among the degrees of freedom in a dynamical system formed of a large number of similar elements, as, for example, the system formed of a large number of molecules of a gas. Lord Kelvin was particularly concerned with the difficulties relative to specific heats and spectral lines. If we accept the doctrine of equipartition, specific heat measurements show that a monatomic gas has only three degrees of freedom per atom. Unless, then, we regard an atom as a material point there are three degrees of freedom unaccounted for. A diatomic gas has, in most cases, a specific heat corresponding to five degrees of freedom per molecule. Even if we regard the two atoms in the molecule as rigidly connected there is one degree of freedom unaccounted for. Furthermore, it is a certain consequence of dynamical theory that to each period of vibration of a dynamical system there corresponds at least one degree of freedom. How to reconcile the limited number of degrees of freedom found by specific heat determinations with the large number required by the complicated spectra of all gases was a problem which he could solve only by giving up the doctrine of equipartition altogether. Now the doctrine of equipartition depends upon two principles: (1) Newtonian dynamics and (2) statistical mechanics. Giving up the doctrine of equipartition was therefore, for him, denying the applicability of statistical mechanics. But he had nothing to offer in its place and so his way of dispelling Cloud No. II was to leave the whole thing darker than before.

A few years before Lord Kelvin gave the lecture to which I have referred Lorentz published his "Theory of Electrical and Optical Phenomena in Moving Bodies." In this paper he showed that by introduction of a special time in a moving system—his "local time"—it was possible to deduce equations which formally satisfied the results of the Michelson-Morley experiment, and other experiments involving electrical and optical phenomena in moving bodies. This was the beginning of the theory of relativity; the development of this theory by Minkowski and particularly by Einstein has indicated that the failure of Newtonian dynamics satisfactorily to account for certain phenomena demands a complete revision

of the geometric concepts of space and time upon which Newton's laws of motion are based.

In the same year that Lord Kelvin discussed the two clouds over the dynamical theories of heat and light Planck published a paper on the theory of radiation. Difficulties connected with the theory of radiation did not seem to attract Lord Kelvin's attention very much, but we now know that his second cloud, that involving the doctrine of equipartition of energy, was also very dense over the dynamical theory of radiation. For how can a medium which can transmit an infinite range of frequencies of vibration, and which therefore must have an infinite number of degrees of freedom, have a finite amount of energy in unit volume if the doctrine of equipartition is to hold for it? The theory developed by Planck led to what we now call the quantum theory. Exchanges of energy between the degrees of freedom, according to the first form of this theory, do not take place continuously as demanded by the differential equations of dynamics, but in some way or other in discrete elements, or quanta.

The reason for speaking of the theory of relativity in connection with the quantum theory is that they both have something in common. They both seem to demand a revision of the laws of dynamics; they both seem to indicate that the Newtonian dynamics is not broad enough to satisfy the requirements of our present knowledge of physical phenomena. And it seems reasonable to hope that a revision of the fundamental conceptions of space, time and matter may be found which will be broad enough to include what we now call the general theory of relativity and the quantum theory. But for the present a special quantum theory seems to be required for the interpretation of a variety of physical phenomena, and an attempt will be made in the following to give an account of some recent developments of this theory.[1]

I. STATISTICAL FOUNDATION FOR THE QUANTUM THEORY

1. The Theory of Stationary States.

As the systems to which the quantum theory is applied consist of enormous numbers of similar elements, or similar dynamical systems, statistical methods are required in dealing with them. The quantum theory had its beginning in the theory of radiation;

[1] The development of the quantum theory and the need for such a theory are very fully discussed in the "Report on Radiation and the Quantum Theory" by J. H. Jeans, Physical Society of London, 1914.

next to this its greatest success has been in its application, by Bohr, to spectroscopy. The leading idea in Bohr's theory is that of stationary states; the atoms of a gas are supposed capable of existing in a number of different states characterized by the radii of the orbits of the electrons circulating about the central positive nucleus of the atom. This suggests the method of applying statistics in a general form. Let us suppose that we have a system consisting of a very large number, N, of similar elements. Each one of the elements we shall suppose is capable of being in one of a number of states, and the elements can pass from one state to another. We shall number the states 1, 2, 3, ..., n, ..., and let ϵ_n be the energy of an element when in the nth state. Suppose that in a certain condition of the system there are N_1 elements in state 1, each having energy ϵ_1, N_2 elements in state 2, each having energy ϵ_2, and, in general, N_n elements in state n, each having energy ϵ_n. If E is the total energy of the system we must have:

$$E = \sum N_n \epsilon_n \tag{1}$$

$$N = \sum N_n \tag{2}$$

Let us put

$$w_n = \frac{N_n}{N} \tag{3}$$

Then w_n is the proportional number of elements in the nth state. Using (3) we can write (1) and (2)

$$E = N \sum w_n \epsilon_n \tag{4}$$

$$1 = \sum w_n \tag{5}$$

We shall now find the probability, P, that the system is in the condition in which there are N_1 elements in the 1st state, N_2 elements in the 2nd state, and, in general, N_n elements in the nth state. The number of different ways that this arrangement can be made is:

$$\frac{N!}{N_1! N_2! \ldots\ldots N_n! \ldots\ldots}$$

Let us assume that the different states are not equally probable, but that p_1, p_2, ... p_n, ... are the probabilities of the respective states. Then the probability that N_1 specified

elements are in the 1st state, N_2 specified elements in the 2nd state, ..., N_n specified elements in the nth state, ... is

$$p_1^{N_1} p_2^{N_2} \ldots \ldots \ldots p_n^{N_n} \ldots \ldots$$

But since the elements are all alike, all we care about is the probability of any N_n elements being in the nth state. This probability is therefore:

$$P = \frac{N!}{N_1!N_2! \ldots \ldots N_n! \ldots} p_1^{N_1} p_2^{N_2} \ldots \ldots p_n^{N_n} \ldots \qquad (6)$$

Now a system left to itself we assume will come to the condition in which the probability of the distribution of the elements among the various states is a maximum. But we know that a physical system left to itself comes to the condition in which the entropy is a maximum. We therefore make the hypothesis that

$$S = f(P)$$

where S is the entropy. This is, of course, not a proof, but statistics never proved anything; all we can say is that it is probable that the entropy will be a function of the probability of the system. Assuming this, we can easily determine what $f(P)$ is. If we have a system consisting of the sum of several systems we know that the entropy of the sum is the sum of the entropies of the separate systems. We know further that the probability for the sum is the product of the probabilities for the separate systems. Suppose we have a mixture of two kinds of elements, 1 and 2; the entropy and the probability are:

$$S = S_1 + S_2$$
$$P = P_1 P_2$$

Hence:

$$f(P_1 P_2) = f(P_1) + f(P_2)$$

Differentiating first by P_1 keeping P_2 constant, and then again by P_2 keeping P_1 constant, we get:

$$f'(P) + Pf''(P) = 0$$

the accents denoting differentiation. From this it follows that

$$S = k \log P + \text{constant} \qquad (7)$$

The numbers of elements in the different states we assume to be large enough so that we can use Stirling's formula:

$$\underset{n = \infty}{\text{Limit}}\ n! = \left(\frac{n}{e}\right)^n \sqrt{2\pi n}$$

From (3), (6), and (7) we find:

$$S = kN\sum w_n \log \frac{p_n}{w_n} + \text{const.} \tag{8}$$

We are now to make S a maximum subject to (4) and (5). We have:

$$\delta S = Nk\sum\left(\log \frac{p_n}{w_n} - 1\right)\delta w_n$$

$$\delta E = 0 = N\sum \epsilon_n \delta w_n$$

$$\delta N = 0 = N\sum \delta w_n$$

Multiplying the second and third of these equations by the indeterminate multipliers λ_1 and λ_2, respectively, and subtracting from the first:

$$\sum\left\{Nk\left(\log \frac{p_n}{w_n} - 1\right) - \lambda_1 N\epsilon_n - \lambda_2 N\right\}\delta w_n = 0$$

Since all the w's are independent of each other, each term in this sum must separately vanish, and it follows that

$$w_n = \alpha p_n e^{-\beta\epsilon_n}$$

in which α and β are two new constants. Substituting this value of w_n in (8), and ignoring the additive constant, we get:

$$S = Nk\alpha\sum p_n e^{-\beta\epsilon_n}(\beta\epsilon_n - \log \alpha)$$

Using (4) and (5)

$$\alpha\sum p_n e^{-\beta\epsilon_n} = 1 \tag{9}$$

$$\alpha N\sum \epsilon_n p_n e^{-\beta\epsilon_n} = E \tag{10}$$

Hence:

$$S = k\beta E - Nk \log \alpha \tag{11}$$

$$dS = k\beta dE + kEd\,\beta - Nkd \log \alpha \tag{12}$$

Divide (10) by (9)

$$E = N\,\frac{\sum \epsilon_n p_n e^{-\beta\epsilon_n}}{\sum p_n e^{-\beta\epsilon_n}} = -N\,\frac{d}{d\beta}\log\sum p_n e^{-\beta\epsilon_n} = N\,\frac{d}{d\beta}\log \alpha$$

Therefore:

$$Ed\,\beta = N\,d \log \alpha$$

By (12)

$$dS = k\,\beta\,d\,E$$

Using the thermodynamic relation

$$dS = \frac{dE}{T}$$

where T is the absolute temperature,

$$\beta = \frac{1}{kT} \tag{13}$$

From (9)

$$\log \alpha = -\log \sum p_n e^{-\beta\epsilon_n}$$

and from (1)

$$S = \frac{1}{T}\left(E + Nk \log \sum p_n e^{-\epsilon_n/kT}\right)$$

Now let us put:

$$F = -NkT \log \sum p_n e^{-\epsilon_n/kT} \tag{14}$$

Then

$$S = \frac{1}{T}(E - F)$$

$$dS = -\frac{1}{T^2}(E - F) + \frac{1}{T}dE - \frac{1}{T}dF = \frac{dE}{T}$$

$$E = F - T\frac{dF}{dT} \tag{15}$$

$$S = -\frac{dF}{dT} \tag{16}$$

and for the specific heat at constant volume, $C_v = dE/dT$

$$C_v = -T\frac{d^2F}{dT^2} \tag{17}$$

The function F is the "Free Energy" of the system.

The proportional number of elements of the system in the nth state is:

$$w_n = \frac{p_n e^{-\epsilon_n/kT}}{\sum p_n e^{-\epsilon_n/kT}} \tag{18}$$

In the expression for the free energy (14) and also in (18) the summation is to be extended over all the different states of the system, each characterized by the energy, ϵ_n, of that state. In the applications of these expressions to systems having more than one

degree of freedom we shall find that the same amount of energy may characterize more than one state; the values of the p's, the probabilities of the different states, may then be regarded as weights assigned to the different states, and taken as proportional to the numbers of distinct states characterized by the same energy.

2. Planck's "Cell" Theory.

The method just described is based upon Bohr's theory of stationary states and leads very directly to an expression for the free energy from which all the thermodynamic properties of the system may be derived. In Planck's[1] application of the quantum theory to systems with many degrees of freedom he has followed more closely the methods of statistical mechanics, and there is an important difference between his theory and that of stationary states.

If we have a dynamical system of f degrees of freedom its state is completely defined at any instant by its f generalized coördinates, $q_1, q_2 \; . \; . \; . \; q_f$, and the corresponding momenta, $p_1, p_2, \; . \; . \; . \; p_f$. The energy of the system, ϵ, is a continuous function of the $2f$ variables:

$$\epsilon = \epsilon(q_1, q_2, \ldots . q_f, p_1, p_2, \ldots . . p_f)$$

The method of statistical mechanics leads to an expression for the free energy of an ensemble of N similar systems:

$$F = -NkT \log \int \ldots . 2f \ldots . \int e^{-\frac{\epsilon}{kT}} \, dq_1, dq_2, \ldots . dq_f dp_1 \ldots . dp_f$$

where the limits of integration are such as to include the whole possible range of variation of the $2f$ variables.

In the $2f$-dimensional space of $q_1, q_2, \; . \; . \; . \; q_f, p_1, p_2, \; . \; . \; . \; p_f$ a single point represents the instantaneous state or phase of the system. The element of volume of this $2f$-dimensional space,

$$dq_1 dq_2 \ldots \ldots . . dq_f dp_1 dp_2, \ldots \ldots dp_f$$

an element of extension-in-phase, using the terminology of Gibbs, we usually regard as indefinitely small. When we consider an ensemble of systems and attempt to define the density-in-phase we meet with the same difficulty that we do in defining the density of a gas consisting of discrete molecules. In the latter problem, the element of volume of 3-dimensional space, while small enough to be treated as a differential element of volume, must still be large enough to contain many molecules, so that the ratio of the

[1] *Berichte deutsche phys. Ges.*, 1915 (438).

number of molecules in it to its volume approaches a finite value. And so in defining the density-in-phase of an ensemble of systems the element of volume $dq_1dq_2 \ldots dq_fdp_1dp_2 \ldots dp_f$ must be considered large enough to contain many representative points. But with this limitation we may regard the element of volume in our $2f$-dimensional space as indefinitely small.

In the quantum theory, on the other hand, Planck makes the hypothesis that the element of extension-in-phase is not merely a mathematical element for purposes of integration, but has a definite physical meaning. In order to define it, Planck proceeds as follows: A single equation between the $2f$ variables, $q_1, \ldots p_f$

$$g_1(q_1, q_2, \ldots p_1, p_2, \ldots p_f) = g_1 = \text{const.} \tag{19}$$

represents a hypersurface in the $2f$-dimensional space. We draw the hypersurfaces corresponding to the values of the constant:

$$g_1 = 0, h, 2h, \ldots\ldots, n_1h, \ldots\ldots\ldots$$

where n_1 is any integer and h is a universal constant. Similarly, we draw other families of hypersurfaces:

$$\left.\begin{array}{l} g_2 = 0, h, 2h, \ldots\ldots, n_2h, \ldots\ldots \\ g_3 = 0, h, 2h, \ldots\ldots, n_3h, \ldots\ldots \\ \ldots\ldots\ldots \\ \ldots\ldots\ldots \end{array}\right\} \tag{20}$$

In this way the whole extension-in-phase is divided into "cells." The "cell" which is bounded by the hypersurfaces

$$\left.\begin{array}{l} g_1 = n_1h \text{ and } g_1 = (n_1 + 1)h \\ g_2 = n_2h \text{ and } g_2 = (n_2 + 1)h \\ \ldots\ldots\ldots \\ \ldots\ldots\ldots \end{array}\right\} \tag{21}$$

we shall denote by the cell $(n_1n_2n_3 \ldots\ldots)$. How these hypersurfaces are to be found will depend upon the dynamical properties of the system and will be discussed later. In general, each degree of freedom furnishes one hypersurface; but it often happens that two or more degrees of freedom lead to the same hypersurface. Such degrees of freedom, with common hypersurfaces, Planck calls "coherent" degrees of freedom. Consider now a differential element, dG, of extension-in-phase which is bounded by the hypersurfaces g_1 and $g_1 + dg_1$, g_2 and $g_2 + dg_2, \ldots\ldots$:

$$dG = \int\int_{g_1}^{g_1+dg_1}\int\int_{g_2}^{g_2+dg_2}\ldots\ldots\int dq_1\, dq_2 \ldots dq_f\, dp_1 \ldots dp_f \tag{22}$$

If it is possible to express this in the form:

$$dG = (dg_1)^i(dg_2)^j(dg_3)^k \ldots\ldots \tag{23}$$

where i, j, k . . . are the numbers of coherent degrees of freedom, so that

$$i + j + k + \ldots\ldots = f$$

and $g_1, g_2,$ . . . . are all independent of each other, then the extension-in-phase bounded by the surfaces $g_1 = 0$ and $g_1 = n_1h$, $g_2 = 0$ and $g_2 = n_2h$, ... will be

$$G = \int_0^{n_1h}\int_0^{n_2h}\ldots\int(dg_1)^i(dg_2)^j\ldots\ldots = (n_1h)^i(n_2h)^j\ldots\ldots \tag{24}$$

The volume of the cell ($n_1n_2n_3$ . . .) is therefore:

$$\left.\begin{aligned} G_{n_1n_2}\ldots &= [(n_1+1)^i - n_1^i][(n_2+1)^j - n_2^j]\ldots\ldots[\quad]h^f \\ &= p_{n_1n_2}\ldots G_{000}\ldots \end{aligned}\right\} \tag{25}$$

where $p_{n_1n_2n_3}$ . . . is the integer

$$p_{n_1n_2n_3}\ldots = [(n_1+1)^i - n_1^i][(n_2+1)^j - n_2^j][(n_3+1)^k - n_{3k}]\ldots \tag{26}$$

and $\quad G_{0000}$ . . . $= h^f =$ volume of cell (0000 . .)

In particular, if all the degrees of freedom are incoherent,

$$i = j = k = \ldots\ldots = 1$$

and

$$p_{n_1n_2n_3}\ldots = 1 \tag{27}$$

We can now proceed exactly as in the theory of stationary states if we let $N_{n_1n_2n_3}$ . . . be the number of systems whose representative points lie in the cell ($n_1n_2n_3$ . . .). Let

$$w_{n_1n_2n_3}\ldots = \frac{N_{n_1n_2n_3}\ldots}{N} \tag{28}$$

where N is the whole number of elements, or systems. Using Boltzmann's definition of the Entropy:

$$S = k \log P \tag{29}$$

where P is the probability of the ensemble of systems, we find, corresponding to (8)

$$S = kN\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty}\ldots\ldots\sum w_{n_1n_2}\ldots\log\frac{p_{n_1n_2}\ldots}{w_{n_1n_2}\ldots} \tag{30}$$

The whole energy of the ensemble of systems is:

$$E = N\sum\ldots\sum w_{n_1n_2}\ldots\,\epsilon_{n_1n_2}\ldots \tag{31}$$

where $\bar{\epsilon}_{n_1n_2n_3}$ . . . represents the mean energy of the system in the cell $(n_1n_2n_3 \ldots)$,

$$\bar{\epsilon}_{n_1n_2}\ldots = \frac{1}{p_{n_1n_2}\ldots h^f}\int_{n_1h}^{(n_1+1)h}\int\int_{n_2h}^{(n_2+1)h\ldots}\int\ldots\int\epsilon(dg_1)^i(dg_2)^j\ldots\ldots \quad (32)$$

We also have:

$$N = N\sum\ldots\sum w_{n_1n_2}\ldots \quad (33)$$

Making $\delta S = 0$ subject to the conditions $\delta E = \delta N = 0$, we find:

$$w_{n_1n_2}\ldots = \frac{p_{n_1n_2}\ldots e^{-\frac{\bar{\epsilon}_{n_1n_2}\ldots}{kT}}}{\sum\ldots\sum p_{n_1n_2}\ldots e^{-\frac{\bar{\epsilon}_{n_1n_2}\ldots}{kT}}} \quad (34)$$

For the free energy we now have:

$$F = -NkT\log\sum\ldots\sum p_{n_1n_2}\ldots e^{-\frac{\bar{\epsilon}_{n_1n_2}\ldots}{kT}} \quad (35)$$

and in terms of F we can express the energy, entropy, and specific heat at constant volume by the expressions (15), (16), and (17). In place of the free energy, F, Planck uses the characteristic function

$$\Psi = -\frac{F}{T}$$

3. There is an essential difference between the two methods that have been described. They represent two different hypotheses. The first hypothesis may be spoken of as the "space-lattice," or stationary state hypothesis, and the second the "cell" hypothesis. In terms of the second hypothesis the first assumes that the representative points of the systems are confined to the surfaces which bound the cells. If f of these surfaces are required then the state of the system is characterized by f integers, n_1, n_2, ..., n_f. We might, therefore, draw f mutually perpendicular axes, and planes parallel to the coördinate planes at unit distance apart. The common intersections of these planes would then give the representative points of possible states of any one of the elements. For this reason we can speak of the first hypothesis as the "space-lattice" hypothesis. In the second hypothesis, on the other hand, the representative point of a system may lie anywhere inside a specified cell, and therefore it is the average energy in a cell which is needed to specify the state of a system. The second hypothesis involves a less radical departure from our cus-

tomary dynamical ideas than the first hypothesis, and appears to be a more natural one to make. But the first hypothesis seems to be required in order to account for line spectra. Possibly the physical conditions of a gas when it emits a line spectrum are such as to allow the existence of these stationary states, while in the case of denser gases, liquids and solids the second hypothesis gives expression, in a measure, to the mutual influence of the molecules.

II. PERIODIC SYSTEMS OF ONE DEGREE OF FREEDOM

4. The quantum hypothesis was first introduced by Planck in his derivation of a formula to express the radiation from a black body as a function of the temperature and frequency. Regarding a medium as made up of simple oscillators which absorb and emit radiation he made the radical hypothesis that these oscillators absorb and emit energy, not continuously as demanded by the laws of electrodynamics, but in whole multiples of a quantum of energy. By means of this hypothesis he obtained for the radiant energy of frequency between ν and $\nu + d\nu$ in unit volume the expression:

$$u_\nu d\nu = \frac{8\pi h\nu^3}{c^3}\frac{d\nu}{e^{\frac{h\nu}{kT}} - 1}$$

In this expression, c is the velocity of light, k the universal constant in Boltzmann's relation $S = k \log P$. The only new constant introduced is h, where $h\nu$ represents a quantum of energy. The quantum of energy, according to this hypothesis, is not a fixed quantum, but its size depends upon the frequency. A few years later Planck developed his second theory in which he assumed that the oscillators absorb energy continuously according to the laws of electrodynamics, but emit energy only in multiples of the quantum, $h\nu$. With this hypothesis he obtained the same expression for the energy density which has been well established by a large amount of experimental work.

The constant, h, introduced by Planck has the dimensions of Energy $\times$ Time; the dimensions are the same as that of angular momentum. In general dynamical theory we are familiar with another function of the same dimensions—Hamilton's Principal Function—which, in the case of a conservative system, is:

$$S = \int_{t_0}^{t} (T - V)dt$$

where T is the kinetic and V the potential energy. Hamilton's Principle states that

$$\delta S = O$$

The physical meaning of this principal function has always been obscure. It occurred to Planck and to Sommerfeld[1] to relate the quantum hypothesis to this Principal Function. The state of affairs is something like that existing with reference to the entropy before Boltzmann's interpretation of it as dependent upon the probability of a system gave it a definite meaning. Sommerfeld made the hypothesis that in any molecular process involving the emission of electrons nothing happened until the principal function attained the definite value:

$$\int_0^\tau (T - V)dt = \frac{h}{2\pi}$$

where h is the constant in Planck's formula. This hypothesis introduces another unknown quantity, τ, the "accumulation time." Applying this hypothesis to the emission of electrons from metallic atoms under the influence of light, assuming that the potential energy was derived from an elastic bond between the atom and electron, and the kinetic energy from the energy of the light waves, Sommerfeld was able to show that the energy of the emitted electron was $E = h\nu$, that is, wholly independent of the energy of the incident light. Of course, the energy of the electron when free from the metal will be less than this by the amount of work done in getting away from the surface. He also applied the same hypothesis to the production of X-rays and γ-rays with good success.

This connection between Hamilton's Principal Function and a quantum hypothesis seems reasonable although it cannot be proved dynamically in such cases where we are concerned with non-periodic phenomena. The principal reason for reluctance in accepting a quantum hypothesis lies in the difficulty of reconciling an emission of energy in discrete elements with the wave theory of light, which is too firmly established to overthrow for any but the most convincing proof. While the new way of stating the quantum hypothesis perhaps does not wholly remove this difficulty, it allows us to treat physical optics, in so far as molecular processes do not need to be considered, in the accustomed way. The quanta that we

[1] "La Theorie der Rayonnement et les Quanta"; *Rapports et Discussions de la Reunion tenue a Bruxelles*, 1911 (313).

deal with are not quanta of energy but quanta of "action." Just what this means physically we do not know. But since the mechanism that emits and absorbs radiation is discontinuous in structure it is not surprising that there should be something discontinuous in the "action."

The important advance that has been made in the quantum theory during the last three or four years is the extension of the application of Hamilton's Principle to periodic systems of many degrees of freedom. Before discussing this problem we shall consider systems of a single degree of freedom in order to show that the new view of the quantum theory yields the same results as the first view of quanta of energy.

5. For a conservative dynamical system we have:

$$\delta\int(T - V)dt = 0$$

If the energy remains constant

$$H = T + V = \text{constant}$$

and we can write this principle:

$$\delta A = \delta\int 2T\,dt = 0$$

where A is the Action. If q is the coördinate, and p the momentum, this becomes:

$$\delta\int p\,dq = 0$$

We now introduce the quantum hypothesis. We assume that the stationary states of the system are those for which the action over a complete period of vibration has the definite values:

$$\int_0^\tau p\,dq = nh \tag{1}$$

where h is Planck's constant, and n any integer. The limits express that the integration is over one complete vibration.

The systems with which we deal are, however, in general, not conservative as they are subject to outside influences. If the external conditions change so slowly that the changes in the system during one complete period may be ignored, it was shown by Ehrenfest[1] that the quantity

$$\frac{2\overline{T}}{\nu}$$

[1] *Phil. Mag.*, 33, 1917 (500).

where $\overline{T}$ is the average value of the kinetic energy during one complete period, is an "adiabatic invariant"; that is, a quantity that remains unaltered during a reversible slow change of external conditions. Since

$$\frac{2\overline{T}}{\nu} = \int_0^\tau p\,dq$$

we see the justification for the hypothesis (1) even when the system is subject to external forces. Without going into the question of adiabatic invariants further, for the present, we shall show the application of this hypothesis.

6. Let us suppose that we have a system of linear one-dimensional oscillators. We can take for the energy of a single oscillator:

$$H = T + V = \frac{1}{2}\mu(\dot{q}^2 + \omega^2 q^2) \tag{2}$$

where

$$\omega = 2\pi\nu = \frac{2\pi}{\tau} \tag{3}$$

$$p = \frac{\partial H}{\partial \dot{q}} = \mu\dot{q}$$

The coördinate q is given at any time by:

$$q = a \sin \omega\,(t - t_0)$$

We thus find:

$$\int_0^\tau p\,dq = \pi a_n^2 \mu\omega = nh \tag{4}$$

in which we have used a_n for the amplitude of the vibration in the nth stationary state. The energy in this state is:

$$\epsilon_n = \frac{1}{2}\mu\, a_n^2\, \omega^2 = n\,h\,\nu \tag{5}$$

We now make use of statistical principles. In the expression (14) of Chapter I for the free energy of a system, the coefficients p_n are the probabilities of the separate states. As we have no reason for believing that one state is more probable than any other we put $p_n = 1$. We therefore get for the free energy of a single oscillator:

$$F = -kT \log \sum_{n=0}^{\infty} e^{-\frac{nh\nu}{kT}}$$

Putting

$$x = e^{-\frac{h\nu}{kT}}$$

we get:

$$F = -kT \log \sum_{n=0}^{\infty} x^n = kT \log (1 - x)$$

or

$$F = kT \log \left(1 - e^{-\frac{h\nu}{kT}}\right) \tag{6}$$

Using (15) we find that the energy of a single oscillator is given by

$$E = \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} \tag{7}$$

This expression for the energy of a single oscillator of frequency ν is the same as that which Planck obtained in his first theory of radiation in which he assumed that both absorption and emission were discontinuous. We see that at the absolute zero of temperature the energy becomes zero. We shall now treat this same problem by the "cell" theory and show that we get a different result.

7. Application of the Cell Theory.

The extension-in-phase is of two dimensions, with coördinates p and q. The energy is:

$$\epsilon = \frac{1}{2}\left(\frac{p^2}{\mu} + \omega^2 \mu q^2\right) \tag{8}$$

and this is at the same time the equation of the path of the representative points in the plane of p, q. The system of hypersurfaces (g) reduces to a single family of plane curves. It is natural, therefore, to choose the ellipses (8) with which to divide the extension-in-phase into cells. The curve $g = 0$ we shall take as the origin, corresponding to $\epsilon = 0$. Our problem then is to express a differential element of extension-in-phase:

$$dG = \int_{g}^{g+dg}\int dq\,dp$$

in the form of dg where g depends only upon the constants of integration of the dynamical equations. With one degree of freedom the motion is determined by the energy, ϵ. g must therefore depend only upon the energy. So that

$$dg = \int_{\epsilon}^{\epsilon+d\epsilon}\int dq\,dp$$

is the difference in the areas of the ellipses (8) for $\epsilon + d\epsilon$ and for ϵ. That is,

$$dg = \frac{2\pi}{\omega} d\epsilon$$

or

$$g = \frac{2\pi}{\omega} \epsilon$$

since we have taken $g = 0$ when $\epsilon = 0$. Thus the bounding surfaces are given by:

$$g = \frac{2\pi}{\omega} \epsilon = nh$$

The mean energy in cell (n) is, by (32),

$$\bar{\epsilon}_n = \frac{1}{p_n h} \int_{nh}^{(n+1)h} \epsilon dg$$

where $p_n h$ is the area of the nth cell, that is:

$$\frac{2\pi}{\omega}(\epsilon_{n+1} - \epsilon_n) = h$$

Hence:

$$\bar{\epsilon}_n = \frac{1}{h} \int_{nh}^{(n+1)h} \frac{\omega}{2\pi} g dg = \frac{\omega h}{2\pi}\left(n + \frac{1}{2}\right)$$

or, since $\nu = \omega/2\pi$,

$$\bar{\epsilon}_n = h\nu\left(n + \frac{1}{2}\right)$$

By (34) we find:

$$w_n = \frac{e^{-\frac{h\nu(n+\frac{1}{2})}{kT}}}{\sum e^{-\frac{h\nu(n+\frac{1}{2})}{kT}}} = \frac{e^{-\frac{nh\nu}{kT}}}{\sum e^{-\frac{nh\nu}{kT}}} = \left(1 - e^{-\frac{h\nu}{kT}}\right) e^{-\frac{nh\nu}{kT}}$$

By (31) the energy in an ensemble of N such oscillators is:

$$E = Nh\nu\left(1 - e^{-\frac{h\nu}{kT}}\right)\sum e^{-\frac{nh\nu}{kT}}\left(n + \frac{1}{2}\right) = Nh\nu\left\{\frac{1}{e^{\frac{h\nu}{kT}} - 1} + \frac{1}{2}\right\}$$

Therefore the mean energy of a single oscillator is:

$$E = \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} + \frac{h\nu}{2} \tag{9}$$

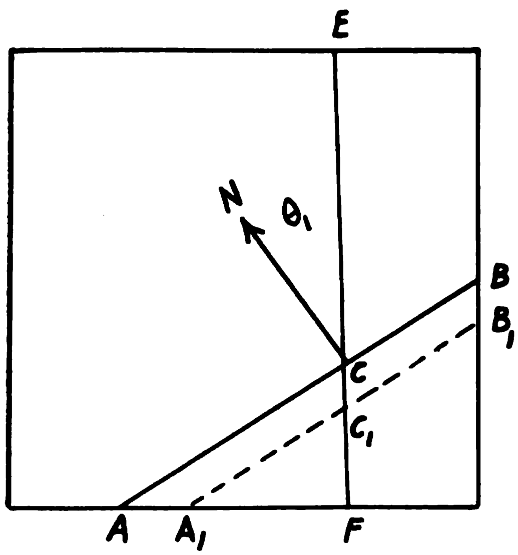
This expression for the mean energy of a single oscillator differs from the one previously obtained by the additional term $h\nu/2$, which is accordingly the energy of the oscillator at the absolute zero of temperature. The latter expression is what Planck ob-

tained for the mean energy of an oscillator by his second theory of radiation, in which he assumed that absorption of radiation was continuous while emission of radiation was discontinuous. There thus appears to be a relation between the space-lattice theory and Planck's first theory of radiation on the one hand, and between the cell theory and Planck's second theory of radiation on the other hand.

The conception of a residual energy in the atoms at the absolute zero of temperature has become quite important in recent years. There is something to be said for the view that a physical basis for the quantum theory may be found in an assumed energy in the atoms at the absolute zero of temperature.[1]

8. Vibration Periods of a Continuous Medium.

The following very simple method of finding the number of vibration frequencies in a continuous medium in the frequency



range from ν to $\nu + d\nu$ is due to Flamm.[2] Consider a cube of the medium whose edge is l. What we want to do is to find the distribution of the vibration frequencies regarding the medium as continuous. Let AB be any wave front, of either longitudinal or transverse waves, and CN the normal drawn in the direction of propagation. In order that AB may be the wave-front of a series of standing waves it is necessary that at E and F the phases should

[1] Ratnowsky, *Annalen der Physik*, 56, 1918 (529).
[2] *Phys. Zeitschrift*, 19, 1918 (116).

be equal or opposite. Let A_1B_1 be a parallel wave-front, one-half a wave-length, λ, behind AB. We then have:

$$CC_1 = \frac{\lambda}{2 \cos \theta_1}$$

The condition for standing waves is:

$$n_1 \, CC_1 = l$$

where n_1 is an integer. Taking into account also the two directions at right angles to FE, we find:

$$\frac{\lambda}{2} n_1 = l \cos \theta_1$$

$$\frac{\lambda}{2} n_2 = l \cos \theta_2$$

$$\frac{\lambda}{2} n_3 = l \cos \theta_3$$

Squaring and adding, and putting $v = \lambda\nu$, where v is the velocity of the waves, we have:

$$n_1^2 + n_2^2 + n_3^2 = \left(\frac{2\,l\,\nu}{v}\right)^2$$

Now from any point as origin draw a system of rectangular axes. The number of points, $x = n_1$, $y = n_2$, $z = n_3$, which satisfy the above relation for which ν lies between o and $\bar{\nu}$ will be the volume of the sphere of radius $2\nu l/v$; that is:

$$N = \frac{4}{3}\pi\left(\frac{2\,l\,\nu}{v}\right)^3$$

The number for which ν lies between ν and $\nu + d\nu$ will be:

$$dN = 8\,\frac{4\pi l^3\nu^2}{v^3}$$

But since n_1, n_2 and n_3 are restricted to be positive integers, we must take the volume of an octant, and hence we get for the number of vibrations having frequencies between ν and $\nu + d\nu$ per unit volume:

$$dN = \frac{4\pi\nu^2}{v^3}$$

Suppose now that the medium can transmit both transverse and longitudinal waves; let their velocities of propagation be v_t and v_l, respectively. Transverse waves may be polarized in two perpendicular directions. Hence we have finally the number of inde-

pendent vibrations per unit volume in the frequency range ν to $\nu + d\nu$:

$$dN = 4\pi\left(\frac{2}{v_t^3} + \frac{1}{v^3}\right)\nu^2 d\nu \qquad (10)$$

9. Planck's Formula

In the ether we can have only transverse waves; put therefore, $v_t = c$, the velocity of light. If, then, we assign to each vibration frequency, ν, the energy given by:

$$E = \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} \qquad (11)$$

we get for the energy in unit volume in the frequency range from ν to $\nu + d\nu$.

$$u_\nu d\nu = \frac{8\pi h\nu^3}{c^3}\frac{d\nu}{e^{\frac{h\nu}{kT}} - 1} \qquad (12)$$

which is Planck's formula.

10. Einstein's Derivation of Planck's Formula.

A more general derivation of Planck's formula, not making use of the consideration of vibratory degrees of freedom of a medium, has been given by Einstein.[1] This derivation is based upon the existence of stationary states and the transition from one to another stationary state under the influence of radiation. To be definite, suppose that we have a system consisting of a large number of molecules of a gas. Each molecule we suppose capable of existing in one of a number of definite states. Let ϵ_n be the energy of a molecule when in the nth state, and N_n the number of molecules in this state, in unit volume.

In unit time a certain number of molecules will pass from the mth to the nth state, even when there is no external radiation present. Let this number be:

$$A_m^n N_m$$

where A_m^n is a constant depending on the states n and m. Each molecule which undergoes this transition emits an amount of energy equal to $\epsilon_m - \epsilon_n$. Now suppose that monochromatic radiation of frequency ν is present; let u_ν be the volume density of this radiation. Under its influence molecules will pass from the mth to the nth state as well as from the nth to the mth state. Let the numbers of these molecules be

$$B_m^n N_m u_\nu \text{ and } B_n^m N_n u_\nu$$

[1] *Deut. Phys. Ges.*, 1916 (318).

respectively. We assume that these numbers are directly proportional to the energy density.

In statistical equilibrium as many molecules must leave state m as enter it. Hence:

$$A_m^n N_m + B_m^n N_m u_\nu = B_n^m N_n u_\nu$$

Now by (18) of Chapter I, the ratio of the numbers of molecules in the nth and mth state is:

$$\frac{N_n}{N_m} = \frac{p_n}{p_m} e^{\frac{\epsilon_m - \epsilon_n}{kT}}$$

Combining these two equations, we get

$$A_m^n p_m = u_\nu \left(B_n^m p_n e^{\frac{\epsilon_m - \epsilon_n}{kT}} - B_m^n p_m \right)$$

We now assume that u_ν approaches infinity when the temperature approaches infinity. It follows from this that

$$B_n^m p_n = B_m^n p_m$$

Putting

$$\alpha_{mn} = \frac{A_m^n}{B_m^n}$$

we get

$$u_\nu = \frac{\alpha_{mn}}{e^{\frac{\epsilon_m - \epsilon_n}{kT}} - 1}$$

According to Wien's displacement law which is derived from classical dynamics and electrodynamics:

$$u_\nu = \frac{\nu^3}{c^3} F\left(\frac{T}{\nu}\right)$$

Hence it follows that α_{mn} must be proportional to ν^3 and $\epsilon_m - \epsilon_n$ must be proportional to ν. Putting

$$\epsilon_m - \epsilon_n = h\nu$$

where h is a constant, we have:

$$u_\nu = \frac{A\nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

where A is a constant. This is Planck's formula.

The particular interest of this derivation of Planck's formula lies in the relation $\epsilon_m - \epsilon_n = h\nu$. This relation was previously assumed by Bohr in his application of the quantum theory to spectral lines. In fact, Bohr's theory is based on the two hypotheses of the existence of stationary states, and this frequency condition.

11. Debye's Theory of the Specific Heat of Solids.

The expression (10) for the number of vibrations in the frequency range from ν to $\nu + d\nu$ assumes that the medium is continuous, and the whole number of vibrations of all frequencies will accordingly be infinite. In an actual solid the atomic structure sets a limit to the whole number of vibrations. If we look upon the atoms as material particles, each atom will have three degrees of freedom, and the maximum number of vibrations will be $3\,N_o$ where N_o is the number of atoms in unit volume. This sets a limit, ν_m, to the highest possible frequency, and we can write:

$$3\,N_o = 4\pi \int_0^{\nu_m} \left(\frac{2}{v_t^3} - \frac{1}{v_l^3}\right) \nu^2 d\nu \tag{13}$$

If we assume that the velocities of the waves are independent of the frequency this gives:

$$\frac{9N_o}{\nu_m^3} = 4\pi \left(\frac{2}{v_t^3} + \frac{1}{v_l^3}\right) \tag{14}$$

We now assign to each frequency, ν, the energy (11), and we therefore get for the energy in unit volume of the solid:

$$E = 4\pi h \int_0^{\nu_m} \left(\frac{2}{v_t^3} + \frac{1}{v_l^3}\right) \frac{\nu^3 d\nu}{e^{\frac{h\nu}{kT}} - 1} \tag{15}$$

Introduce a "characteristic temperature"

$$\Theta = \frac{h\nu_m}{k} \tag{16}$$

and put

$$x = \frac{h\nu}{kT}$$

We can then write:

$$E = 9\,N_o\,kT \left(\frac{T}{\Theta}\right)^3 \int_0^{\frac{\Theta}{T}} \frac{x^3 dx}{e^x - 1}$$

The specific heat at constant volume is:

$$C_v = \frac{dE}{dT} = 9\,N_o k \left\{ 4 \left(\frac{T}{\Theta}\right)^3 \int_0^{\frac{\Theta}{T}} \frac{x^3 dx}{e^x - 1} - \frac{\Theta}{T} \frac{1}{e^{\frac{\Theta}{T}} - 1} \right\} \tag{17}$$

For high temperatures this gives:

$$C_v = 3N_o k \tag{18}$$

which is the Dulong-Petit law. For very low temperatures, we find, since

$$\int_0^\infty \frac{x^3dx}{e^x - 1} = \frac{\pi^4}{90}$$

$$C_v = \frac{2\pi^4}{5} N_0 k \left(\frac{T}{\Theta}\right)^3 \qquad (19)$$

Thus at low temperatures the specific heat of solids is proportional to the cube of the absolute temperature. This is found to be in good agreement with experimental results.

The characteristic temperature for any substance is the only constant at our disposal in (17); its value can therefore be determined from the variation of the specific heat with the temperature. It can also be determined by the use of (14), which gives:

$$\Theta^3 = \frac{9N_0h^3}{4\pi k^3} \frac{2v_l^3 + v_t^3}{v_l^3 v_t^3} \qquad (20)$$

The right-hand side can be determined from a knowledge of the elastic constants of the substance. The following table shows the nature of the agreement between these two methods of determining Θ[1].

	By Specific Heat Measurements	From Elastic Constants
Lead	88	75
Cadmium	168	174
Silver	215	220
Copper	315	341
Aluminium	398	413
Iron	453	484
Sylvite	230	227
Rock Salt	281	305
Fluorite	474	510
Pyrite	645	696

The agreement is remarkably good when one considers the approximations involved in the comparison.

12. In the last few years a large amount of evidence has been obtained from the study of X-ray diffraction effects that all solids, and particularly crystalline solids, have a space-lattice structure, with the atoms at the lattice points. A good deal of progress has been made in the dynamics of such a space-lattice structure, particularly in regard to the periods of vibration.[2] From this point

[1] Schrodinger, *Phys. Zeit.*, 20, 1919 (476).

[2] Born, "Dynamik der Krystallgitter," Leipzig, 1915.

of view Born and Karman[1] have calculated the specific heats of a number of crystals, and their results agree rather better with experiment than those obtained from Debye's theory in which the solid is considered a continuous medium.

If we look upon the heat energy of a solid as the energy of the elastic vibrations we should expect the thermal conductivity of a solid to be mainly conditioned by these vibrations. According to this view, Debye[2] has made an attempt at a theory of thermal conductivity in solids. There are many difficulties in the way of getting a complete theory, but it is a promising field for further work, and it seems probable that electric conduction in metals will be found to be closely related to these elastic vibrations.

III. SYSTEMS WITH MANY DEGREES OF FREEDOM

GENERAL DYNAMICAL THEORY

The application of the quantum theory to systems with many degrees of freedom depends upon certain dynamical methods which will be briefly described. A full account of these methods is given by Charlier,[3] whose treatment of them will be closely followed.

13. The method of Separation of the Variables.

Consider a dynamical system of f degrees of freedom, with the coördinates $q_1, q_2, \ldots q_f$; the corresponding velocities $\dot{q}_1, \dot{q}_2, \ldots \dot{q}_f$; and the momenta $p_1, p_2, \ldots p_f$. If the kinetic energy, T, is expressed in terms of the coördinates and velocities, then

$$p_k = \frac{\partial T_{q\dot{q}}}{\partial \dot{q}_k};\ k = 1,2,\ldots f$$

By means of these f relations it is possible to express the kinetic energy in terms of the coördinates and momenta, in which case it may be denoted by T_{qp}. The potential energy, V, is a function of the coördinates only. The sum of the kinetic energy and the potential energy is

$$H = T_{qp} + V$$

If the time, t, does not enter explicitly in this equation, H will be constant throughout the motion and we can write:

$$H(p_1, p_2, \ldots p_f, q_1, q_2, \ldots q_f) = \alpha_1 \qquad (1)$$

[1] *Phys. Zeit.*, 13, 1912 (294); 14, 1913 (15, 65).

[2] "Vortrage über die Kinetische Theorie der Materie und der Elektrizitat", Göttingen, 1914.

[3] Charlier, "Die Mechanik des Himmels", Band I, Leipzig, 1902.

where α_1 is the constant energy of the system. The Hamiltonian equations of motion are:

$$\frac{\partial H}{\partial p_k} = \dot{q}_k \quad \frac{\partial H}{\partial q_k} = -\dot{p}_k \tag{2}$$

The Hamilton-Jacobi method of solution of dynamical problems consists in writing a single partial differential equation in place of the $2f$ differential equations (2). This equation is:

$$H\left(\frac{\partial W}{\partial q_1}, \frac{\partial W}{\partial q_2}, \ldots \ldots \frac{\partial W}{\partial q_f}, q_1, q_2, \ldots . q_f\right) = \alpha_1 \tag{3}$$

where $\partial W/\partial q_k$ replaces p_k in (1). The complete solution of (3) will contain f arbitrary constants of integration, besides the constant α_1. One of these constants will be an additive constant, and so the solution of (3) may be written:

$$W = W(q_1, q_2, \ldots . q_f, \alpha_1, \alpha_2, \ldots \ldots \alpha_f) + \alpha_{f+1} \tag{4}$$

where the α's are the constants of integration. The solution of the dynamical problem is then contained in the equations:

$$\frac{\partial W}{\partial \alpha_1} = t + \beta_1, \frac{\partial W}{\partial \alpha_2} = \beta_2, \frac{\partial W}{\partial \alpha_3} = \beta_3, \ldots . \frac{\partial W}{\partial \alpha_f} = \beta_f \tag{5}$$

where the β's are f other arbitrary constants. We thus have in (5) $2f$ constants of integration which is the required number for a system of f degrees of freedom.

If in equation (3) $\partial W/\partial q_k$ enters only in squares Stäckel showed that this equation could always be integrated by a separation of variables and the motion of the system completely described. Assume therefore that the Hamilton-Jacobi equation (3) is of the form

$$\frac{1}{2}\left\{A_1\left(\frac{\partial W}{\partial q_1}\right)^2 + A_2\left(\frac{\partial W}{\partial q_2}\right)^2 + \ldots . A_f\left(\frac{\partial W}{\partial q_f}\right)^2\right\} + V - \alpha_1 = O \tag{6}$$

in which the A's are functions of the q's. Assume a solution of this equation:

$$W = Q_1 + Q_2 + \ldots \ldots \ldots + Q_f$$

where Q_k depends only on q_k. Putting

$$\frac{\partial Q_k}{\partial q_k} = Q_k'$$

(6) may be written:

$$\frac{1}{2}\sum_{k=1}^{f} A_k Q_k'^2 + V - \alpha_1 = O \tag{7}$$

Differentiate this equation in turn by $\alpha_1, \alpha_2, \ldots\ldots \alpha_f$:

$$\left.\begin{aligned} A_1 \frac{\partial Q_1'^2}{\partial \alpha_1} + A_2 \frac{\partial Q_2'^2}{\partial \alpha_1} + \ldots\ldots\ldots + A_f \frac{\partial Q_f'^2}{\partial \alpha_1} &= 2 \\ A_1 \frac{\partial Q_1'^2}{\partial \alpha_2} + A_2 \frac{\partial Q_2'^2}{\partial \alpha_2} + \ldots\ldots\ldots + A_f \frac{\partial Q_f'^2}{\partial \alpha_2} &= 0 \\ \ldots\ldots\ldots \\ \ldots\ldots\ldots \\ A_1 \frac{\partial Q_1'^2}{\partial \alpha_f} + A_2 \frac{\partial Q_2'^2}{\partial \alpha_f} + \ldots\ldots\ldots + A_f \frac{\partial Q_f'^2}{\partial \alpha_f} &= 0 \end{aligned}\right\} \tag{8}$$

If we now put

$$\frac{\partial Q_k'^2}{\partial \alpha_i} = \varphi_{ki}(q_k) \tag{9}$$

we can solve (8) for the A's:

$$A_k = \frac{2}{\Delta} \frac{\partial \Delta}{\partial \varphi_{k1}} \tag{10}$$

where Δ is the determinant:

$$\Delta = \begin{vmatrix} \varphi_{11}\ \varphi_{21}\ \varphi_{31} \ldots\ldots\ldots\ldots \varphi_{f1} \\ \varphi_{12}\ \varphi_{22} \ldots\ldots\ldots\ldots\ldots \varphi_{f2} \\ \ldots\ldots\ldots \\ \ldots\ldots\ldots \\ \varphi_{1f}\ \varphi_{2f} \ldots\ldots\ldots\ldots\ldots \varphi_{ff} \end{vmatrix} \tag{11}$$

This determinant may be expanded:

$$\Delta = \sum_{k=1}^{f} \varphi_{k1} \frac{\partial \Delta}{\partial \varphi_{k1}}$$

or

$$1 = \sum_{k=1}^{f} \frac{1}{\Delta} \varphi_{k1} \frac{\partial \Delta}{\partial \varphi_{k1}} \tag{12}$$

(7) may therefore be written:

$$V = \sum_{k=1}^{f} \frac{1}{\Delta} \frac{\partial \Delta}{\partial \varphi_{k1}} (\alpha_1 \varphi_{k_1} - Q_k'^2)$$

If we put

$$\psi_k = Q_k'^2 - \alpha_1 \varphi_{k_1} \tag{13}$$

ψ_k will depend only on q_k, and we will have:

$$V = -\sum_{k=1}^{f} \frac{1}{\Delta} \frac{\partial \Delta}{\partial \varphi_{k_1}} \psi_k \tag{14}$$

We can show now that

$$W = \sum_{k=1}^{f} \int \sqrt{2\psi_k + 2\sum_{1}^{f} \alpha_i \varphi_{ki}}\, dq_k \tag{15}$$

is the complete solution of the Hamilton-Jacobi equation. For, from (15)

$$\left(\frac{\partial W}{\partial q_k}\right)^2 = Q_k'^2 = 2\,\psi_k + 2\sum_{i=1}^{f} \alpha_i\, \varphi_{ki}$$

Putting this in (7), and using (12) and (14) we get

$$\frac{1}{\Delta}\sum_{k=1}^{f} \frac{\partial\Delta}{\partial\varphi_{k1}} \sum_{i=2}^{f} \alpha_i\varphi_{ki} = \frac{1}{\Delta}\sum_{i=2}^{f} \alpha_i \sum_{k=1}^{f} \varphi_{ki}\frac{\partial\Delta}{\partial\varphi_{k1}}$$

But from the properties of determinants:

$$\sum_{k=1}^{f} \varphi_{ki}\frac{\partial\Delta}{\partial\varphi_{k1}} \quad \begin{aligned} &= 1 \text{ if } i = 1 \\ &= 0 \text{ if } i \neq 1 \end{aligned}$$

Therefore (15) satisfies the Hamilton-Jacobi equation, and contains the required number of integration constants, $\alpha_1, \alpha_2, \ldots \alpha_f$.

From (5) and (15) the complete solution of the dynamical problem is:

$$\left.\begin{aligned} t + \beta_1 &= \sum_{k=1}^{f} \int \frac{\varphi_{k1} dq_k}{\sqrt{2\psi_k + 2\sum_{i=1}^{f} \alpha_i\varphi_{ki}}} \\ \beta_j &= \sum_{k=1}^{f} \int \frac{\varphi_{kj} dq_k}{\sqrt{2\psi_k + 2\sum_{i=1}^{f} \alpha_i\varphi_{ki}}} \\ j &= 2\ 3, \ldots f \end{aligned}\right\} \tag{16}$$

The momentum corresponding to q_k is:

$$p_k = \pm \sqrt{2\psi_k + 2\sum_{i=1}^{f} \alpha_i\varphi_{ki}(q_k)} \tag{17}$$

and by (15)

$$W = \int \sum_{k=1}^{f} p_k dq_k \tag{18}$$

the sign of p_k being taken the same as that of dq_k.

14. **Conditionally Periodic Systems. Angle Variables.**

Let us write:

$$\Phi_k(q_k) = 2\psi_k + 2\sum_{i=1}^{f} \alpha_i\varphi_{ki} \tag{19}$$

Then differentiating (16) we get:

$$\left.\begin{aligned} dt &= \sum_{k=1}^{f} \frac{\varphi_{k1}dq_k}{\sqrt{\Phi_k(q_k)}} \\ o &= \sum_{k=1}^{f} \frac{\varphi_{kj}dq_k}{\sqrt{\Phi_k(q_k)}} \\ j &= 2, 3, \ldots f \end{aligned}\right\} \tag{20}$$

Let $q_1^o, q_2^o, \ldots, q_f^o$ be the initial values of the coördinates. Let a_k and b_k be two neighboring roots of the equation

$$\Phi_k(q_k) = o \tag{21}$$

such that

$$a_k < q_k^o < b_k$$

In all of our applications the roots a_k and b_k will be simple roots and so we can put

$$\Phi_k(q_k) = (q_k - a_k)(b_k - q_k)\Psi_k(q_k) \tag{22}$$

Writing

$$\frac{dq_k}{\sqrt{(q_k - a_k)(b_k - q_k)}} = m_k du_k \tag{23}$$

and

$$F_{ki}(q_k) = \frac{\varphi_{ki}}{\sqrt{\Psi_k}}$$

we get:

$$\begin{aligned} dt &= F_{11}(q_1)m_1du_1 + F_{21}(q_2)m_2du_2 + \ldots\ldots F_{f1}(q_f)m_fdu_f \\ O &= F_{12}(q_1)m_1du_1 + F_{22}(q_2)m_2du_2 + \ldots\ldots F_{f2}(q_f)m_fdu_f \\ &\ldots\ldots\ldots \\ &\ldots\ldots\ldots \\ O &= F_{1f}(q_1)m_1du_1 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots F_{ff}(q_f)m_fdu_f \end{aligned}$$

Solving these equations:

$$\frac{dt}{E} = \frac{m_1du_1}{\dfrac{\partial E}{\partial F_{11}}} = \frac{m_2du_2}{\dfrac{\partial E}{\partial F_{21}}} = \ldots\ldots\ldots = \frac{m_fdu_f}{\dfrac{\partial E}{\partial F_{f1}}} \tag{24}$$

where E is the determinant formed from the F's.

In the transformation (23) we have introduced new variables, the u's, with arbitrary constants, the m's. The latter we can therefore choose in a special way. Let us therefore take for the m's ± 1, the sign being so chosen that, according to (24) as t increases all the u's shall increase. This assumes that, as may be proved, neither E nor any of its derivatives can vanish. It follows then from (23) that if initially $a_k < q_k^0 < b_k$, q_k will always remain less than b and greater than a_k and that dq_k will vanish for $q_k = a_k$ and for $q_k = b_k$.

The motion expressed by the equations (16) in the case of simple roots of the radical is therefore such that each coördinate oscillates between two limits. Such a motion is called a Libration. If the roots of any of the radicals in (16) are multiple it may be shown that the motion of the corresponding coördinate is one in which the coördinate approaches and reaches after an infinite time a limiting value. Such motions are called limitation motions.

A particular case is furnished by cyclic coördinates, that is, coördinates which do not themselves appear in the expression for the energy but only the corresponding velocities or momenta. Such coördinates increase indefinitely with the time, but they have the property of repeating their values with the period 2π.

If we let any one of the coördinates, q_k, increase to its maximum value, b_k, then diminish to a_k, and finally return to its initial value, the left-hand sides of (16) will each increase by

$$\omega_{kj} = 2\int_{a_k}^{b_k} \frac{\varphi_{kj} dq_k}{\sqrt{\Phi_k(q_k)}} \tag{25}$$

where $j = 1, 2, 3, \ldots, f$. In particular, the time will increase by ω_{k1}. Equations (16) express $t + \beta_1, \beta_2, \beta_3, \ldots, \beta_f$ as functions of the q's, since these are the upper limits in the indefinite integrals. Conversely, we can look upon these equations as expressing the q's as functions of $t + \beta_1, \beta_2, \ldots \beta_f$. When so regarded the q's are periodic functions of the β's with the periods given by (25). We can therefore introduce a change of variables given by:

$$\left.\begin{aligned} 2\pi(t + \beta_1) &= \sum_{k=1}^{f} \omega_{k1} w_k \\ 2\pi\beta_j &= \sum_{k=1}^{f} \omega_{kj} w_k \qquad j = 2, 3, \ldots f \end{aligned}\right\} \tag{26}$$

The new variables, the w's, so introduced, have the property that when one of them, say w_k, is increased by 2π each β_j is increased by ω_{kj}, while q_k is left unaltered.

If we solve equations (26) for the w's, we get:

$$w_k = \omega_k t + \delta_k \tag{27}$$

where

$$\omega_k = \frac{2\pi}{\Delta}\frac{\partial\Delta}{\partial\omega_{k1}} \tag{28}$$

$$\delta_k = \frac{2\pi}{\Delta}\sum_{j=1}^{f}\beta_j\frac{\partial\Delta}{\partial\omega_{kj}} \tag{29}$$

$$\Delta = \begin{vmatrix} \omega_{11} \ldots\ldots\ldots \omega_{f1} \\ \ldots\ldots\ldots\ldots \\ \omega_{1f} \qquad\quad \omega_{ff} \end{vmatrix} \tag{30}$$

The new variables, the w's, are thus variables that increase indefinitely with the time, and are the so-called angle variables of the system. The q's we have seen are periodic in the w's with the period 2π; the q's may be periodic in the time. The condition for this is easily found. Let T be the periodic time. Then when t is increased by T, w_k is increased by $\omega_k T$. If this quantity is a whole multiple of 2π then the motion of the system in the coördinates q will be periodic in time with the period T. We then have the k equations:

$$\frac{2\pi}{\Delta}\frac{\partial\Delta}{\partial\omega_{k1}}T = 2\pi m_k$$

where m_k is an integer. Multiplying by ω_{kj} and summing for all the k's,

$$\frac{T}{\Delta}\sum_{1}^{f}{}_k\,\omega_{kj}\frac{\partial\Delta}{\partial\omega_{k1}} = \sum_{1}^{f}{}_k\, m_k\omega_{kj}$$

But we have:

$$\frac{1}{\Delta}\sum_{1}^{f}{}_k\,\omega_{kj}\frac{\partial\Delta}{\partial\omega_{k1}} = \begin{matrix} 1 \text{ if } j = 1 \\ 0 \text{ if } j \neq 1 \end{matrix}$$

Therefore, in order that the motion of the system may be periodic in the time, the following relations must hold:

$$\begin{aligned} T &= m_1\omega_{11} + m_2\omega_{21} + \ldots\ldots + m_f\omega_{f1} \\ O &= m_1\omega_{12} + m_2\omega_{22} + \ldots\ldots + m_f\omega_{f2} \\ &\ldots\ldots \\ &\ldots\ldots \\ O &= m_1\omega_{1f} + m_2\omega_{2f} + \ldots\ldots + m_f\omega_{ff} \end{aligned} \tag{31}$$

For the reason that systems of the type here considered may be periodic in the time they are called conditionally periodic systems.

15. Canonical Equations in the Angle Variables.

Let us form the quantities:

$$I_k = 2\int_{a_k}^{b_k} \Phi_k dq_k = 2\int_{a_k}^{b_k} p_k dq_k \tag{32}$$

These quantities depend only upon the integration constants, $\alpha_1, \alpha_2, \ldots, \alpha_f$. Conversely, we can regard the α's as functions of the I's. In particular, the energy, α_1, may be expressed:

$$\alpha_1 = H(I_1, I_2, \ldots\ldots, I_f) \tag{33}$$

Differentiating (33) by $\alpha_1, \alpha_2, \ldots\ldots, \alpha_f$, we get:

$$\begin{aligned} 1 &= \sum_1^f {}_k \frac{\partial H}{\partial I_k}\frac{\partial I_k}{\partial \alpha_1} = \sum \frac{\partial H}{\partial I_k}\omega_{k1} \\ O &= \sum_1^f {}_k \frac{\partial H}{\partial I_k}\frac{\partial I_k}{\partial \alpha_j} = \sum \frac{\partial H}{\partial I_k}\omega_{kj} \\ j &= 2, 3 \ldots f \end{aligned} \tag{34}$$

Since by (25) and (32)

$$\frac{\partial I_k}{\partial \alpha_j} = \omega_{kj} \tag{35}$$

Differentiate equations (26) by the time:

$$\begin{aligned} 2\pi &= \sum \omega_{k1}\dot{w}_k \\ o &= \sum \omega_{kj}\dot{w}_k \quad j = 2, 3, \ldots f \end{aligned} \tag{36}$$

Comparing (34) and (36) we find:

$$\dot{w}_k = \frac{\partial H}{\partial \frac{I_k}{2\pi}} \tag{37}$$

Since the energy, H, is independent of the w's, and the I's are all constant, we have:

$$\frac{\partial H}{\partial w_k} = O = \frac{d}{dt}\frac{I_k}{2\pi}$$

The system of equations:

$$\frac{dw_k}{dt} = \frac{\partial H}{\partial \frac{I_k}{2\pi}} \qquad\qquad (38)$$
$$\frac{d}{dt}\frac{I_k}{2\pi} = \frac{\partial H}{\partial w_k}$$

is a Hamiltonian çanonical sytem, with coördinates, the w's, and constant momenta, the $\frac{I\text{'s}}{2\pi}$.

If in the solution of the Hamilton-Jacobi equation,

$$W = \sum Q_k(q_k, \ \alpha_1\alpha_2 \ldots . \alpha_f),$$

we introduce the I's in place of α's, we have:

$$t + \beta_1 = \frac{\partial W}{\partial \alpha_1} = \sum \frac{\partial W}{\partial I_k}\frac{\partial I_k}{\partial \alpha_1}$$
$$= \sum \omega_{k1}\frac{\partial W}{\partial I_k} \quad \text{by (35)}$$
$$= \frac{1}{2\pi}\sum \omega_{k1} w_k \quad \text{by (26)}$$

It follows therefore that

$$w_k = \frac{\partial W}{\partial \frac{I_k}{2\pi}} \qquad\qquad (39)$$

This enables us to determine the angle variables for a conditionally periodic system.

In equation (27) ω_k is the "mean motion" corresponding to the angle variable w_k. By the first of (38)

$$\omega_k = \frac{dw_k}{dt} = 2\pi\frac{\partial H}{\partial I_k} \qquad\qquad (40)$$

An important property of conditionally periodic systems proved by Stackel is that if the paths of the dynamical system in the multi-dimensional volume defined by the f relations

$$a_k < q_k < b_k \qquad\qquad (41)$$

are traced, then these paths will fill this volume everywhere equally dense. If, however, the motion is periodic in time, *i. e.*, if relations (31) are satisfied, with the m's all integers, then the dynamical path is a single closed curve, and a single parameter—*e. g.*, the length of arc of this closed curve measured from a fixed point—defines

the instantaneous state of the system. In terms of the angle variables, w_k, if the motion of the system is periodic only a single angle variable is needed. In general, if a smaller number of angle variables are needed, than the number of degrees of freedom of the system, the paths of the system will not fill the volume defined by (41) but will be confined to a hypersurface of less than f dimensions. Systems having this property are called degenerate "entartete."

IV. QUANTUM CONDITIONS FOR SYSTEMS WITH MANY DEGREES OF FREEDOM

16. Quantum Conditions According to Sommerfeld and Epstein.

The principle of Least Action states

$$\delta \int 2T\, dt = O$$

where T is the kinetic energy of a conservative system. If T is expressed in terms of the coördinates and velocities, we have, by Euler's theorem:

$$2T = \sum_{k=1}^{f} p_k \dot{q}_k$$

Therefore:

$$\delta \sum \int p_k \dot{q}_k dt = \delta \sum \int p_k dq_k = 0$$

In a conditionally periodic system where the variables are separable we have seen that p_k may be expressed in terms of q_k, and the f constants of integration. By supposing that the system is constrained to move in such a way that only one of the coördinates, q_k, varies, we will have:

$$\delta \int p_k dq_k = O$$

And as q_k may be any one of the f coördinates there will be f such equations.

Now the special quantum hypothesis is that the integral:

$$I_k = 2 \int_{a_k}^{b_k} p_k dq_k = n_k h \qquad (1)$$

a_k and b_k are the two libration limits of the coördinate q_k, h is

Planck's constant, and n_k is any integer. If q_j is a cyclic angle coördinate, the corresponding hypothesis is made:

$$I_j = \int_0^{2\pi} p_j dq_j = n_j h \tag{2}$$

We see that the conditions (1) and (2) are a natural extension of the quantum condition for a periodic system of a single degree of freedom (§ 5). This extension seems to have been first suggested by W. Wilson,[1] although he made no general application of it.

It has been shown by Burgers[2] that when the system is not conservative but is subject to outside influences the quantities I_k defined by (1) are adiabatic invariants, that is, quantities which remain constant during a slow change in the external conditions. In the case of degenerate systems there are certain linear combinations of the I's, with integral coefficients, which remain invariant.

In the application of these quantum conditions the energy is to be expressed in terms of the I's, and, therefore, by (1) and (2) in terms of integers. In degenerate systems these integers will enter only in certain linear combinations, and we shall see that this leads to a difficulty in defining the probability of a state of the system characterized by the values of the integers that enter into the expression for the energy. A particular case is furnished by a system which is periodic in the time with the period T. The integral of action taken over a complete period is:

$$I = \sum \int_0^T p_k \dot{q}_k dt$$

Now:

$$I_k = 2\int_{a_k}^{b_k} p_k dq_k = \int_0^{\omega_{k1}} p_k \dot{q}_k dt \cdot$$

where ω_{k1} is defined by (25) of the last chapter. If now the system is periodic, ω_{k1} must be a submultiple of T, *i. e.*, $m_k \omega_{k1} = T$, where m_k is an integer. Hence it follows:

$$I = m_1 I_1 + m_2 I_2 + \ldots\ldots\ldots m_f I_f \tag{3}$$

where m_1, m_2, . . . are integers without a common divisor. If then we write the single quantum condition

$$I = nh \tag{4}$$

[1] *Phil. Mag.*, 29, 1915 (795).

[2] *Ibid.*, 33, 1917 (514).

where n has all integral values, we see that this is equivalent to the f quantum conditions

$$I_k = n_k h$$

provided that at least one of the m's is unity.

Degenerate systems have the property that separation of the variables is possible in more than one system of coördinates, and as a result the quantum conditions in the present form are not unique in defining the stationary states, although there is no difficulty about expressing the energy in the required form.

17. Planck's Quantum Conditions.[1]

We have already seen (§ 2) that Planck makes more direct use of the methods of statistical mechanics in applying the quantum theory to systems of many degrees of freedom. It has been shown by Epstein[2] that when separation of the variables is possible Planck's method leads to the same quantum conditions as given above.

Planck's method is to divide the extension-in-phase

$$G = \int\int \ldots \int dq_1 dq_2 \ldots dq_f dp_1 \ldots dp_f$$

into finite cells by means of the hypersurfaces:

$$g_1 = n_1 h$$
$$g_2 = n_2 h$$
$$\ldots$$

in such a way that an element of extension-in-phase may be expressed as

$$dG = dg_1 dg_2 \ldots$$

If we consider the path of the system in the $2f$ dimensional space of the p's and the q's, then, according to Planck, none of the paths are to cross any of the hypersurfaces $g_1, g_2, \ldots$ A path which begins on one hypersurface must remain on that hypersurface. The equations to the path are obtained by eliminating the time from the canonical equations of motion:

$$\frac{\partial H}{\partial p_k} = \frac{dq_k}{dt} \quad \frac{\partial H}{\partial q_k} = -\frac{dp_k}{dt}$$

and are:

$$dq_1 : dq_2 \ldots \ldots dq_f : dp_1 : dp_2 \ldots \ldots dp_f$$
$$= \frac{\partial H}{\partial p_1} : \frac{\partial H}{\partial p_2} : \ldots \ldots \frac{\partial H}{\partial p_f} : -\frac{\partial H}{\partial q_1} : -\frac{\partial H}{\partial q_2} : \ldots \ldots : -\frac{\partial H}{\partial q_f}$$

[1] *Annalen der Physik*, **50**, 1916 (385).
[2] *Berlin Berichte*, 1918 (435).

The solution of these equations furnishes *2f-1* integrals:

$$u_1 = H = \text{const.}$$
$$u_2 = \text{const.}$$
$$\cdots\cdots$$

where $u_1, u_2, \ldots\ldots$ are functions of the coördinates and momenta. The path of the system is determined by the u's, and the position of the system on the path is determined by a single parameter, which may be the time, or the length of the arc measured from a fixed point.

In forming the integrals (u) of the equations of motion, certain singular surfaces will be found. As the paths of the system cannot cross any of these singular surfaces it is natural to take these for the surfaces:

$$g_1 = 0, \; g_2 = 0, \; g_3 = 0, \; \ldots\ldots\ldots$$

In order to find the other hypersurfaces of these families Planck assumes that by means of constraints the number of degrees of freedom of the system is successively reduced until only one is left. We can then, for a single degree of freedom, proceed as in § 7 in order to find the other surfaces.

Consider now an element of extension-in-phase:

$$dG = \int_{g_1}^{g_1+dg_1}\!\!\int\!\!\int_{g_2}^{g_2+dg_2}\!\!\int \ldots\ldots\ldots \int dq_1 dq_2 \ldots\ldots\ldots dp_1 \ldots\ldots dp_f \qquad (5)$$

In a conditionally periodic system the momenta are functions of the corresponding coördinate and f constants, $\alpha_1, \alpha_2, \ldots\ldots \alpha_f$. By means of the f equations:

$$I_k = 2\int_{a_k}^{b_k} p_k dq_k$$

we can express the α's in terms of the I's. Introduce new variables into (5), the q's and I's in place of the q's and p's. This gives:

$$dG = \int \ldots\ldots \int D dq_1 \ldots\ldots dq_f dI_1 \ldots\ldots dI_f$$

where D is the functional determinant:

$$D = \begin{vmatrix} \dfrac{\partial p_1}{\partial I_1} & \dfrac{\partial p_2}{\partial I_1} & \cdots\cdots\cdots & \dfrac{\partial p_f}{\partial I_1} \\ \\ \dfrac{\partial p_1}{\partial I_f} & \cdots\cdots\cdots\cdots & & \dfrac{\partial p_f}{\partial I_f} \end{vmatrix}$$

With respect to q_k the integration limits are from a_k to b_k and back again. On developing the determinant D the element of extension-in-phase becomes the sum of a number of terms of the type:

$$2^f dI_1 dI_2 \ldots dI_f \int_{a_1}^{b_1} \frac{\partial p_1}{\partial I_i} dq_1 \int_{a_2}^{b_2} \frac{\partial p_2}{\partial I_j} dq_2 \ldots\ldots \int_{a_f}^{b_f} \frac{\partial p_f}{\partial I_s} dq_f$$

Now consider any factor:

$$2\int_{a_k}^{b_k} \frac{\partial p_k}{\partial I_r} dq_k$$

Since p_k vanishes at the limits, this may be written:

$$\frac{\partial}{\partial I_r} 2\int_{a_k}^{b_k} p_k dq_k = \frac{\partial I_k}{\partial I_r} = \begin{matrix} 0 \text{ if } k \neq r \\ 1 \text{ if } k = r \end{matrix}$$

We thus find:

$$dG = dI_1\, dI_2 \ldots\ldots dI_f$$

If then we take, in general:

$$g_k = I_k = 2\int_{a_k}^{b_k} p_k dq_k = n_k h \tag{6}$$

we will have the quantum conditions in the form given by Sommerfeld and Epstein and also, in this special case, in the form given by Planck. We thus see that when separation of the variables is possible the quantum conditions (1) and (2) furnish at the same time the bounding surfaces for the probability cells.

Systems with coherent degrees of freedom according to Planck (see § 2) correspond to degenerate systems. In particular, if the system is periodic all the degrees of freedom are coherent.

18. Schwarzschild's Quantum Conditions.

In terms of the angle variables, w_k, and the corresponding momenta, $I_k/2\pi$, Schwarzschild[1] has written quantum conditions in a very plausible form. The dynamical system being specified by the $2f$ coördinates:

$$w_1,\ w_1, \ldots\ldots\ldots w_f,\ \frac{I_1}{2\pi},\ \frac{I_2}{2\pi} \ldots\ldots\ldots,\ \frac{I_f}{2\pi}$$

the element of extension-in-phase is:

$$\frac{1}{(2\pi)^f}\int \ldots\ldots \int dw_1 dw_2 \ldots dw_f\, dI_1 \ldots dI_f$$

[1] *Berlin Berichte*, 1916 (548).

A natural finite element of extension-in-phase, an element of probability in the sense used by Planck, is one in which each angle variable, w_k, has the limits 0 and 2π. The I's being constants, with the dimension of an "action" their limits will be taken to be

$$n_k h \text{ and } (n_k + 1)h$$

We then have, integrated over a "cell:"

$$\frac{1}{2\pi}\int\int dw_k dI_k = I_k = n_k h$$

and therefore in the case of conditionally periodic systems Schwarzchild's quantum conditions are the same as those of Sommerfeld and Epstein.[1]

V. THE ROTATIONAL SPECIFIC HEAT OF DIATOMIC GASES

19. It is known from the work of Eucken that at low temperatures the specific heat of hydrogen approaches the value appropriate, on the equipartition theory, to a monatomic gas. The simplest model of a hydrogen molecule is that of two atoms at the ends of a rigid axis. Rotation about the axis is assumed not to play any part in the thermal behavior of the gas and so there are five degrees of freedom—three translational and two rotational. If, then, as the temperature falls the rotational degrees of freedom disappear, the results of Eucken will qualitatively be accounted for.

In applying the quantum theory we can suppose that each molecule is a dynamical system of two degrees of freedom which can rotate about a fixed point, and that the two principal moments of inertia perpendicular to the axis are equal to each other. The motion of such a system under the action of no forces is a uniform rotation about an axis fixed in space; the system is therefore a degenerate system (§ 15). In order explicitly to bring in the two degrees of freedom we may suppose that a directive force acts upon the molecules and then pass to the limit by putting the external force equal to zero. We shall therefore assume the molecules to be magnetic doublets in a field of magnetic force.[2] We might equally well for the present purpose suppose the molecules to be gyroscopes in a gravitational field, but the solution of the former problem will be of use when we consider the theory of paramagnetism.

20. A Magnetic Doublet Rotating about a Fixed Point in a Uniform Magnetic Field.

[1] *Annalen der Physik*, 51, 1916 (168).

[2] Reiche, *Ibid.*, 54, 1917 (401).

Taking the direction of the external field as the axis of a system of polar coördinates, the direction of the axis of the doublet is fixed by the angles θ and ψ; θ is the inclination of the axis of the doublet to the direction of the field, and ψ is the azimuth of the axis of the doublet with respect to a fixed plane containing the direction of the field.

Let I be the moment of inertia of the doublet about any axis perpendicular to the axis of the doublet, and μ the moment of the magnet. Then the kinetic energy is:

$$T = \frac{1}{2} I(\dot{\theta}^2 + \sin^2 \theta \dot{\psi}^2)$$

and the potential energy

$$V = \mu H(1 - \cos \theta)$$

where H is the strength of the field. The momenta corresponding to the coördinates θ, ψ are:

$$p_\theta = \frac{\partial T}{\partial \dot{\theta}} = I\dot{\theta};\ p_\psi = \frac{\partial T}{\partial \dot{\psi}} = I \sin^2 \theta \dot{\psi}$$

and

$$T_{pq} = \frac{1}{2I}\left(p_\theta^2 + \frac{1}{\sin^2 \theta} p_\psi^2\right)$$

The Hamilton-Jacobi equation is therefore:

$$\frac{1}{2}\left\{\frac{1}{I}\left(\frac{\partial W}{\partial \theta}\right)^2 + \frac{1}{I \sin^2 \theta}\left(\frac{\partial W}{\partial \psi}\right)^2\right\} + \mu H(1 - \cos \theta) - \alpha_1 = O \quad (1)$$

where α_1 is the whole energy.

The angle ψ is a cyclic coördinate, and we therefore have:

$$p_\psi = \frac{\partial W}{\partial \psi} = \alpha_2 = \text{const.} \quad (2)$$

We get separation of the variables immediately by writing:

$$W = \alpha_2 \psi + W_\theta \quad (3)$$

where W_θ depends only on θ, and is determined by:

$$W_\theta = \int d\theta \sqrt{2\alpha_1 I - 2\mu HI(1 - \cos \theta) - \frac{\alpha_2^2}{\sin^2 \theta}} \quad (4)$$

The complete solution of the dynamical problem is therefore given by

$$t + \beta_1 = I \int \frac{d\theta}{\sqrt{2\alpha_1 I - \frac{\alpha_2^2}{\sin^2 \theta} - 2\mu HI(1 - \cos \theta)}}$$

$$\beta_2 = \psi - \alpha_2 \int \frac{d\theta}{\sin^2\theta \sqrt{2\alpha_1 I - \frac{\alpha_2^2}{\sin^2\theta} - 2\mu HI(1-\cos\theta)}}$$

where β_1 and β_2 are two constants.

We shall take the quantum conditions in the form (1) and (2) of the previous chapter. They give:

$$2\int_{\theta_1}^{\theta_2} p_\theta d\theta = n_1 h \tag{5}$$

$$\int_0^{2\pi} p_\psi d\psi = n_2 h = 2\pi\alpha_2 \tag{6}$$

where θ_1 and θ_2 are the two roots of

$$2\alpha_1 I - 2\mu H(1-\cos\theta) - \frac{\alpha_2^2}{\sin^2\theta} = 0 \tag{7}$$

between which the initial value of θ lies.

In (5) put $\cos\theta = x$; since $p_\theta = \frac{\partial W}{\partial\theta}$ we find by (4)

$$2\int_{x_1}^{x_2} \frac{dx}{1-x^2}\sqrt{2\alpha_1 I - \alpha_2^2 - 2\alpha_1 I x^2 - 2\mu HI(1-x)(1-x^2)} = n_1 h \tag{8}$$

Of the three roots of the cubic under the radical two lie between $x = +1$ and $x = -1$, and the third is less than -1. Therefore for x_1 and x_2 we must take the first two roots.

We shall now suppose that the external field, H, is small enough so that we can neglect higher powers than the first. Expanding, we get:

$$2\int_{x_1}^{x_2} \frac{dx}{1-x^2}\sqrt{2\alpha_1 I - \alpha_2^2 - 2\alpha_1 I x^2} - 2\mu HI \int_{x_1}^{x_2} \frac{(1-x)dx}{\sqrt{2\alpha_1 I - \alpha_2^2 - 2\alpha_1 I x^2}} = n_1 h$$

If now instead of taking for x_1 and x_2 the two roots of the cubic which are between $+1$ and -1 we take the two roots of the quadratic

$$2\alpha_1 I x^2 = 2\alpha_1 I - \alpha_2^2$$

as our integration limits our results will be valid as far as terms of the first order in H. This quantum condition may therefore be written:

$$2\sqrt{2\alpha_1 I}\int_{-a}^{+a} \frac{\sqrt{a^2 - x^2}}{1-x^2}dx - \frac{2\mu HI}{\sqrt{2\alpha_1 I}}\int_{-a}^{+a}\frac{(1-x)dx}{\sqrt{a^2-x^2}} = n_1 h \tag{9}$$

where

$$a^2 = \frac{2\alpha_1 I - \alpha_2^2}{2\alpha_1 I}$$

Integrating:

$$2\pi\left\{\sqrt{2\alpha_1 I} - |\alpha_2|\right\} - \frac{2\pi\mu HI}{\sqrt{2\alpha_1 I}} = n_1 h \tag{10}$$

In this expression $|\alpha_2|$ means the absolute value of α_2. Remembering that the constant α_2 is the constant momentum p_ψ, for every positive p_ψ there must be a corresponding negative value, and the quantum conditions must be the same for equal positive and negative values.

We can now get the expression for the energy in the various stationary states characterized by the two integers n_1 and n_2. By (6) the two possible directions of rotation in ψ may be taken care of by allowing n_2 to have both positive and negative integral values. From (10) and (6) we get, if $H = 0$:

$$\alpha_1 = \epsilon_{n_1 n_2} = \frac{\{n_1 + |n_2|\}^2 h^2}{8\pi^2 I} \tag{11}$$

and using this value in the small term containing H:

$$\epsilon_{n_1 n_2} = \frac{\{n_1 + |n_2|\}^2 h^2}{8\pi^2 I} + \mu H \tag{12}$$

21. Application to Rotational Specific Heats.

We have now determined the energy in the stationary states defined by the two integers n_1 and n_2. If, however, we characterize the stationary states by their energy we see that we can get the same energy by different combinations of two integers n_1 and n_2. Now it is a question whether these different combinations giving the same energy should be counted as different states or not. There are several possibilities to be considered. Let us put

$$\frac{h^2}{8\pi^2 I} = A$$

There is only one way of getting the energy 0, *i. e.*, $n_1 = 0$ and $n_2 = 0$. The energy A we can get in three ways: $n_1 = 0, n_2 = 1$; $n_1 = 1, n_2 = 0$; $n_1 = 0, n_2 = -1$. Counting the states in which n_2 has negative values as distinct states means that we regard opposite azimuthal rotations as giving rise to distinct states. The energy $4A$ we can get in five ways, as follows:

$$n_1 = 2, \quad 1, \quad 1, \quad 0, \quad 0$$
$$n_2 = 0, \ +1, \ -1, \ +2, \ -2$$

and, in general, the energy n^2A we can get in $2n + 1$ ways. If, therefore, we assume that each of these states is equally probable, then in the expression for the free energy of a system of N such molecules I (14), we should have:

$$p_n = 2n + 1$$

Therefore:

$$F = -NkT \log \sum_0^\infty (2n + 1)\, e^{-n^2\sigma} \tag{13}$$

where

$$\sigma = \frac{h^2}{8\pi^2 kIT} \tag{14}$$

If we put

$$Q(\sigma) = \sum_0^\infty{}_n (2n + 1)\, e^{-n^2\sigma} \tag{15}$$

we find by I (17) for the specific heat at constant volume resulting from the two rotational degrees of freedom:

$$C_r = Nk\sigma^2 \frac{d^2}{d\sigma^2} \log Q(\sigma) \tag{16}$$

For very low temperatures (σ large) we can take:

$$Q(\sigma) = 1 + 3e^{-\sigma}$$

which gives:

$$C_r = 3Nk\sigma^2 e^{-\sigma} \tag{17}$$

and this approaches o with T. For high temperatures (σ small) we can transform the sum in (15) to an integral:

$$Q(\sigma) = \int_0^\infty (2n + 1)e^{-n^2\sigma} dn = \frac{1}{\sigma} + \frac{1}{2}\sqrt{\frac{\pi}{\sigma}} \tag{18}$$

and this gives for the rotational specific heat:

$$C_r = Nk - \frac{1}{8} Nk\sqrt{\pi\sigma} \tag{19}$$

Since $\frac{1}{2} Nk$ is, on the equipartition theory, the value of the specific heat corresponding to one degree of freedom, the value just found approaches that corresponding to two degrees of freedom at high temperatures. Qualitatively, the results found by Eucken are thus accounted for; but when the series for $Q(\sigma)$ is evaluated for

intermediate temperatures it is found that C_r rises to a maximum with increasing temperature, then diminishes, and finally rises again approaching the value given by (19). As there is no experimental evidence for such a behavior we are led to make a different assumption about the probability of the different states.

The assumption that leads to an expression which most closely represents the experimental results is the following: The state corresponding to *o* energy is not to be counted as a possible state. So we take $p_0 = 0$. No state in which $n_2 = 0$ is to be considered a possible state. This means that we do not count those states in which there is no azimuthal rotation. We are thus led to take

$$p_n = 2n$$

and by taking

$$Q(\sigma) = \sum_{1}^{\infty}{}_n\, 2ne^{-n^2\sigma} \tag{20}$$

we can use (16) to determine the rotational specific heat. Whether or not we count opposite azimuthal rotations as giving rise to distinct states makes no difference as far as the specific heat is concerned, for we would get the same result by taking

$$Q(\sigma) = \sum_{1}^{\infty} ne^{-n^2\sigma}$$

For very low temperatures (σ large) we get, taking the first two terms in the sum:

$$C_r = 18Nk\sigma^2e^{-3\sigma} \tag{21}$$

this also approaches *o* with T. For high temperatures (σ small)

$$Q(\sigma) = \int_0^{\infty} 2ne^{-n^2\sigma}dn = \frac{1}{\sigma}$$

giving

$$C_r = Nk \tag{22}$$

This is the value demanded by the equipartition theory.

The following table, given by Reiche,[1] contains values of C_r/Nk at different temperatures computed from (16) and (20), and also experimental values of the same quantity determined by Eucken and by Scheel and Heuse. σ is computed from the observed value at 100° absolute, which gives:

$$\sigma = 188.7$$

[1] *Annalen der Physik*, 58, 1919 (657).

The moment of inertia of the hydrogen molecule is, therefore, by (14)

$$I = 2.095 \ 10^{-41}$$

T	$\frac{C_r}{NK}$ Computed	$\frac{C_r}{NK}$ Experimental
35	0.000	0.000
40	0.000	0.000
45	0.001	0.010
50	0.003	0.015
60	0.014	0.005
65	0.026	0.030
70	0.041	0.060
80	0.084	0.081
82	0.095	0.106
85	0.113	0.116
90	0.147	0.141
91	0.154	0.136
100	0.222	0.222
110	0.302	0.323
126	0.433	...
135	0.504	...
145	0.578	...
157	0.654	...
172	0.727	...
189	0.795	...
196.5	0.817	0.711
236	0.901	...
273.1	0.936	0.937

Except at the temperature 196.5 the agreement is well within the limits of experimental error. But at this temperature the discrepancy is too large to be accounted for by experimental errors. The experimental values are obtained by subtracting from the measured specific heat the specific heat due to the three translational degrees of freedom, *i. e.*, $3/2 \ kN$. This assumes that the specific heat of a monatomic gas is independent of the temperature. Experimental determinations by Scheel and Heuse,[1] however, show that the specific heat of helium diminishes at low temperatures. It seems probable that the application of the quantum theory to monatomic gases may lead to valuable results. Keesom[2] has considered this problem by the same method that Debye used for determining the specific heat of solids (§ 11), and Planck[3] has also taken up the problem using his "cell" theory, but no definite conclusions have been reached.

[1] *Annalen der Physik*, 40, 1913 (473).
[2] *Phys. Zeit.*, 14, 1913 (665).
[3] *Berlin Berichte*, 1916 (653).

It is of interest to compare the value of the moment of inertia of the hydrogen molecule obtained above with that obtained from Bohr's theory. According to Bohr,[1] if $2b$ is the distance between the two atoms in the hydrogen molecule:

$$b = \frac{1}{9-\sqrt{3}}\frac{1}{m}\left(\frac{h}{\pi e}\right)^2$$

where e and m are the charge and mass of an electron. If M is the mass of a hydrogen atom,

$$I = 2\,Mb^2$$

This gives

$$I = 2.82\ 10^{-41}$$

22. Application of the "Cell" Theory.[2]

The "space-lattice" theory we have seen leads to different results depending upon what are taken as the probabilities of the stationary states of the system. The "cell" theory, on the other hand, leads to a definite result which is the same as that obtained above by choosing the stationary states in an arbitrary way.

It has been shown (§ 17) that the hypersurfaces for dividing the extension-in-phase into cells may, in conditionally periodic systems, be determined by the same equations that determine the stationary states on the space-lattice theory. We therefore take for these hypersurfaces:

$$g_1 = 2\int_{\theta_1}^{\theta_2}\sqrt{2\alpha_1 I - \frac{\alpha_2^2}{\sin^2\theta} - 2\mu HI(1-\cos\theta)}.\ d\theta = n_1 h \qquad (23)$$

$$g_2 = 2\pi\alpha_2 = n_2 h \qquad (24)$$

As our extension-in-phase is of four dimensions, one more family of surfaces is necessary in order to divide it into cells. It is obvious that the third family of surfaces must be planes through the direction of the external field, H. And as the angle ψ is a cyclic coordinate, everything is symmetrical about this direction, and our cells may therefore be taken as closed tubes, bounded in any azimuthal plane by the curves g_1 and g_2.

$g_2 = 0$, which is equivalent to $p_\psi = 0$, or to $n_2 = 0$, divides the whole extension-in-phase into two halves, a positive half and a negative half. To each positive cell there corresponds an equal negative cell. We need therefore consider only the positive cells.

[1] *Phil. Mag.*, **28**, 1913 (863).

[2] Rotsajn, *Annalen der Physik*, **57**, 1918 (81).

The value of g_1 we have already found (10) in the case where H is small. For the positive half we thus have:

$$g_1 = 2\pi\left\{\sqrt{2\alpha_1 I} - \alpha_2\right\} - \frac{2\pi\mu H I}{\sqrt{2\alpha_1 I}} \tag{25}$$

$$g_2 = 2\pi\alpha_2 \tag{26}$$

and from these we find:

$$\alpha_1 = \frac{(g_1 + g_2)^2}{8\pi^2 I} + \mu H \tag{27}$$

The mean value of the energy α_1 in the cell $(n_1 n_2)$ is:

$$\bar{\epsilon}_{n_1 n_2} = \frac{\int_{n_1 h}^{(n_1+1)h}\int_{n_2 h}^{(n_2+1)h} \alpha_1 dg_1 dg_2}{\int\int dg_1 dg_2}$$

or:

$$\bar{\epsilon}_{n_1 n_2} = \frac{1}{8\pi^2 h^2 I}\int_{n_1 h}^{(n_1+1)h}\int_{n_2 h}^{(n_2+1)h}(g_1 + g_2)^2 dg_1 dg_2 + \mu H$$

$$= \frac{h^2}{8\pi^2 I}\left\{(n_1 + n_2 + 1)^2 + \frac{1}{6}\right\} + \mu H \tag{28}$$

Taking $H = 0$, and determining the free energy of N such systems by means of I (35), we have:

$$F = -NkT\log\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty} 2e^{-\sigma\left\{(n_1+n_2+1)^2+\frac{1}{6}\right\}}$$

where

$$\sigma = \frac{h^2}{8\pi^2 IkT}$$

and where the factor 2 comes from including the negative cells. Writing this

$$F = -NkT\log Q(\sigma)$$

we have for the rotational specific heat:

$$C_r = Nk\sigma^2\frac{\partial^2}{\partial\sigma^2}\log Q(\sigma)$$

where

$$Q(\sigma) = \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty} 2e^{-\sigma(n_1+n_2+1)^2}$$

The double sum can be transformed at once into a single sum:

$$Q(\sigma) = \sum_{1}^{\infty} 2ne^{-\sigma n^2}$$

This is the same result we found before by choosing the stationary states in a particular way.

VI. APPLICATION OF THE QUANTUM THEORY TO PARAMAGNETISM

23. In considering the application of the quantum theory to the rotational specific heat of diatomic gases we saw that the "cell" theory led to a result in fair agreement with experiment, while the space-lattice theory led to the same result only by making an arbitrary assumption about the probabilities of the stationary states. The application of the space-lattice theory to paramagnetism has been treated by Smekal,[1] while the cell theory has been treated by Reiche[2] and by Rotsajn.[3] The results of these investigations are decidedly in favor of the cell theory and we shall therefore consider the problem of paramagnetism from that point of view.

We regard each molecule as a magnetic doublet of moment μ as in the last chapter, and we shall use here the same notation and some of the results. If there are N molecules per unit volume, and if $\overline{\cos\theta}$ gives the average inclination of the axes of the doublets to the external field, H, the resultant magnetic moment in the direction of the field is

$$M = N\mu\,\overline{\cos\theta}$$

and the magnetic susceptibility is

$$\kappa = \frac{M}{H} = \frac{N\mu\,\overline{\cos\theta}}{H} \tag{1}$$

Our problem then is to determine $\overline{\cos\theta}$. To do this we first find the mean value of $\cos\theta$ in the cell $(n_1 n_2)$. Let this be $\overline{\cos\theta_{n_1 n_2}}$. The proportional number of systems in the cell $(n_1 n_2)$ is $w_{n_1 n_2}$, where the latter is given by I (34). Averaging $\overline{\cos\theta_{n_1 n_2}}$ over all the cells, we get:

$$\overline{\cos\theta} = \sum_{n_1} \sum_{n_2} w_{n_1 n_2}\,\overline{\cos\theta_{n_1 n_2}} \tag{2}$$

[1] *Annalen der Physik.*, **57**, 1918 (376).
[2] *Ibid.*, **54**, 1917 (401).
[3] *Ibid.*, **57**, 1918 (81).

Having found this, (1) gives the susceptibility directly.

24. Average Value of cos θ in a single cell.
We have:

$$\overline{\cos\theta_{n_1n_2}} = \frac{1}{h^2}\int\int\int\int \cos\theta\, d\theta d\psi dp_\theta dp_\psi$$

where the limits of integration are such as to include the cell (n_1n_2) and by I (27), h^2 is the volume of the cell. The integrations will be a little easier if we write this:

$$\overline{\cos\theta_{n_1n_2}} = 1 - \frac{1}{h^2}\int\int\int\int (1-\cos\theta) d\theta d\psi dp_\theta dp_\psi$$

We can integrate with respect to ψ at once, between the limits 0 and 2π. Since

$$dp_\psi = d\alpha_2 = \frac{dg_2}{2\pi}$$

we have:

$$\overline{\cos\theta_{n_1n_2}} = 1 - \frac{1}{h^2}\int_{n_2h}^{(n_2+1)h} dg_2\left[2\int_{\theta_1}^{\theta_2} p_\theta(1-\cos\theta)d\theta\right]_{g_1=n_1h}^{g_1=(n_1+1)h} \quad (3)$$

Now from V (4) we get:

$$\int_{\theta_1}^{\theta_2} p_\theta(1-\cos\theta)d\theta = \int_{\theta_1}^{\theta_2}(1-\cos\theta)\sqrt{2\alpha_1 I - \frac{\alpha_2^2}{\sin^2\theta} - 2\mu HI(1-\cos\theta)}\, d\theta \quad (4)$$

As before, we put $\cos\theta = x$, and develop in a series, keeping terms of the first order only in H. This gives:

$$\int_{\theta_1}^{\theta_2} p_\theta(1-\cos\theta)d\theta = \int_{x_1}^{x_2}\frac{dx}{1+x}\sqrt{2\alpha_1 I - \alpha_2^2 - 2\alpha_1 I x^2} - \mu HI\int_{x_1}^{x_2}\frac{(1-x)^2dx}{\sqrt{2\alpha_1 I - \alpha_2^2 - 2\alpha_1 I x^2}}$$

where

$$\begin{matrix} x_1 \\ x_2 \end{matrix} = \begin{matrix} - \\ + \end{matrix}\sqrt{\frac{2\alpha_1 I - \alpha_2^2}{2\alpha_1 I}}$$

Integrating, we find

$$\int_{\theta_1}^{\theta_2} p_\theta(1-\cos\theta)d\theta = \pi\{\sqrt{2\alpha_1 I} - \alpha_2\} - \frac{\pi\mu HI}{2\sqrt{2\alpha_1 I}}\left(3 - \frac{\alpha_2^2}{2\alpha_1 I}\right) \quad (5)$$

From V (26) and (27)

$$\alpha_1 = \frac{(g_1 + g_2)^2}{8\pi^2 I} + \mu H$$

$$\alpha_2 = \frac{g_1}{2\pi}$$

Using these values in (5) and keeping terms of the first order only in H we get:

$$\left[2\int_{\theta_1}^{\theta_2} p_\theta(1 - \cos\theta)d\theta\right]_{g_1 = n_1 h}^{g_1 = (n_1+1)h} = \left[g_1 - 2\pi^2\mu HI\,\frac{2g_1g_2 + g_1^2}{(g_1+g_2)^3}\right]_{g_1 = n_1 h}^{g_1 = (n_1+1)h}$$

$$= h - 2\pi^2\mu HI\,\frac{2(n_1 + 1)hg_2 + (n_1+1)^2h^2}{\{(n_1+1)h + g_2\}^2}$$

$$+ 2\pi^2\mu HI\,\frac{2\pi_1 hg_2 + n_1^2h^2}{(n_1h + g_2)^3} \tag{6}$$

This must be multiplied by dg_2 and integrated between the limits n_2h and $(n_2 + 1)h$. This gives:

$$\left.\begin{aligned}\overline{\cos\theta_{n_1n_2}} = \frac{2\pi^2\mu HI}{h^2}\Bigg\{\frac{(n_1+1)^2}{2}&\left[\frac{1}{(n_1+n_2+1)^2} - \frac{1}{(n_1+n_2+2)^2}\right]\\ -\frac{n_1^2}{2}&\left[\frac{1}{(n_1+n_2+1)^2} - \frac{1}{(n_1+n_2)^2}\right]\end{aligned}\right\} \tag{7}$$

$$+ 2(n_1+1)\left[\frac{1}{n_1+n_2+1} - \frac{1}{n_1+n_2+2}\right]$$

$$+ 2n_1\left[\frac{1}{n_1+n_2+1} - \frac{1}{n_1+n_2}\right]\Bigg\}$$

The mean value of $\cos\theta$ in the cell (o, o) must be treated as a special case, since the last expression is indeterminate for $n_1 = n_2 = 0$. By putting $n_2 = 0$ in (6) and integrating the result with respect to g_2 between the limits of 0 and h, we find:

$$\overline{\cos\theta_{o,o}} = \frac{5}{4}\,\frac{\pi^2\mu HI}{h^2} \tag{8}$$

25. Average Value of $\cos\theta$ for all the doublets.

By I (34) the proportional number of doublets in the cell (n_1, n_2) is:

$$w_{n_1n_2} = \frac{e^{-\frac{\overline{\epsilon_{n_1n_2}}}{KT}}}{\sum_0^\infty {}_{n_1}\sum_0^\infty {}_{n_2}\, e^{-\frac{\overline{\epsilon_{n_1n_2}}}{kT}}} \tag{9}$$

In V (28) we have found:

$$\overline{\epsilon_{n_1 n_2}} = \frac{h^2}{8\pi^2 I}\left\{(n_1 + n_2 + 1)^2 + \frac{1}{6}\right\} + \mu H \tag{10}$$

Putting:

$$\sigma = \frac{h^2}{8\pi^2 IkT} \tag{11}$$

we can write this:

$$w_{n_1 n_2} = \frac{e^{-\sigma(n_1+n_2+1)^2}}{\sum_0^\infty{}_{n_1} \sum_0^\infty{}_{n_2} e^{-\sigma(n_1+n_2+1)^2}}$$

$$= \frac{e^{-\sigma(n_1+n_2+1)^2}}{S_o} \tag{12}$$

where

$$S_o = \sum_0^\infty{}_{n_1} \sum_0^\infty{}_{n_2} e^{-\sigma(n_1+n_2+1)^2} = \sum_1^\infty n e^{-\sigma n^2} \tag{13}$$

By (2) we get for the average value of $\cos\theta$ for all the doublets:

$$S_o \overline{\cos\theta} = \frac{5}{4}\frac{\pi^2 \mu H I}{h^2} e^{-\sigma}$$

$$+ \frac{\pi^2 \mu H I}{h^2} \sum_0^\infty{}_{n_1} \sum_0^\infty{}_{n_2} \left\{(n_1+1)^2\left[\frac{1}{(n_1+n_2+2)^2} - \frac{1}{(n_1+n_2+1)^2}\right]\right.$$

$$\left. - n_1^2\left[\frac{1}{(n_1+n_2+1)^2} - \frac{1}{(n_1+n_2)^2}\right]\right\} e^{-\sigma(n_1+n_2+1)^2}$$

$$+4\frac{\pi^2 \mu H I}{h^2} \sum_0^\infty{}_{n_1} \sum_0^\infty{}_{n_2} \left\{(n_1+1)\left[\frac{1}{n_1+n_2+1} - \frac{1}{n_1+n_2+2}\right]\right. \tag{14}$$

$$\left. + n_1\left[\frac{1}{n_1+n_2+1} - \frac{1}{n_1+n_2}\right]\right\} e^{-\sigma(n_1+n_2+1)^2}$$

In the double sums the term $n_2 = n_1 = 0$ is to be omitted as the cell (o, o) is taken care of in the first term.

The second double sum will readily be seen to be o, while the first double sum may be written as a single sum:

$$\frac{1}{3} \sum_2^\infty{}_n \frac{e^{-\sigma n^2}}{n(n^2 - 1)}$$

We therefore have:

$$S_o \overline{\cos\theta} = \frac{5}{4}\frac{\pi^2 \mu H I}{h^2} e^{-\sigma} + \frac{1}{3}\frac{\pi^2 \mu H I}{h^2} \sum_2^\infty{}_n \frac{e^{-\sigma n^2}}{n(n^2-1)} \tag{15}$$

The magnetic susceptibility is now, by (1)

$$\kappa = \frac{N\mu^2\pi^2 I}{h^2} \frac{\frac{5}{4}e^{-\sigma} + \frac{1}{3}\sum_{2}^{\infty}\frac{e^{-\sigma n^2}}{n(n^2-1)}}{\sum_{1}^{\infty} ne^{-\sigma n^2}} \tag{16}$$

Low Temperature.

In the case when T is small, and σ large, we may take only the first terms in the sums and find:

$$\kappa = \frac{5N\mu^2\pi^2 I}{4h^2} \tag{17}$$

According to this, therefore, the magnetic susceptibility approaches a limiting value for $T = 0$, $\sigma = \infty$.

High Temperatures.

In this case σ is small, and we can take:

$$\sum_{1}^{\infty} ne^{-\sigma n^2} = \int_{0}^{\infty} ne^{-\sigma n^2} dn = \frac{1}{2\sigma} \tag{18}$$

In the sum in the numerator of (16) we may take $e^{-\sigma n^2} = 1$, since for large values of n the terms become very small. We then have:

$$\sum_{2}^{\infty}\frac{1}{n(n^2-1)} = \frac{1}{2}\sum_{2}^{\infty}\frac{1}{n(n-1)} - \frac{1}{2}\sum_{2}^{\infty}\frac{1}{n(n+1)} = \frac{1}{4} \tag{19}$$

Hence:

$$\kappa = \frac{1}{3}\frac{N\mu^2}{kT} \tag{20}$$

This is the value of the magnetic susceptibility given by Langevin's kinetic theory of paramagnetism.

The general formula (16) for the magnetic susceptibility contains two unknown quantities, μ, the magnetic moment of the molecules, and I, the moment of inertia. It is possible to choose these constants so that this formula represents fairly well the rather limited experimental determinations of magnetic susceptibility over any extensive temperature range.

Kamerlingh Onnes and Oosterhuis have measured the magnetic susceptibilities of a number of paramagnetic salts over a wide temperature range, and the following table gives their results, together with the values of the susceptibilities determined by Reiche from formula (16). The values of the moment of inertia

of the molecule and the magnetic moment which give the best representation of the results are also given, as is the limiting value of the susceptibility, κ_0, for $T = 0$ from (17).

Substance	T	κ Calculated	κ Observed
Anhydrous Manganese	14.4	637.9 10^{-6}	636 10^{-6}
Sulphate	17.8	614.9	627
$MnSO_4$	20.1	597.8	603
$I = 1.99\ 10^{-40}$	64.9	315.1	314.5
$\mu = 4.35\ 10^{-21}$	77.4	277.5	274.8
$\kappa_0 = 657.7\ 10^{-6}$	169.6	142.7	144.2
	293.9	86.8	87.8
Crystallized Manganese	14.4	1233.10^{-6}	1233 10^{-6}
Sulphate	17.8	1014	1021
$MnSO_4 + 4\ H_2O$	20.1	905	914
$I = 3.14\ 10^{-39}$	64.9	293.2	292
$\mu = 3.65\ 10^{-21}$	70.5	270.6	270
$\kappa_0 = 7294\ 10^{-6}$	77.4	247.3	247
	169.6	114.5	111.5
	288.7	67.6	66.3
Anhydrous Ferric	64.0	177.6 10^{-6}	177.1 10^{-6}
Sulphate	70.5	167.6	167.3
$Fe_2(SO_4)_3$	77.4	156.7	157.2
$I = 1.40\ 10^{-40}$	169.6	85.1	85.6
$\mu = 3.42\ 10^{-21}$	289.8	53.3	53.3
$\kappa_0 = 286.4\ 10^{-6}$			
Crystallized Ferrous	14.7	760.5 10^{-6}	756.10^{-6}
Sulphate	20.3	568.7	571
$FeSO_4 + 7\ H_2O$	64.6	189.8	191
$I = 2.23\ 10^{-39}$	77.3	159.5	160
$\mu = 2.94\ 10^{-21}$	292.3	42.4	42.4
$\kappa_0 = 3365.10^{-6}$			

VII. APPLICATION OF THE QUANTUM THEORY TO SPECTRAL LINES

26. The greatest success of the quantum theory has been in its application to line spectra. The two following hypotheses were made by Bohr, and these are fundamental in this application of the quantum theory.

I. The atoms of a radiating gas can exist in certain discrete non-radiating stationary states.

II. An atom may pass from one to another stationary state of less energy, and in this transition monochromatic radiation of frequency ν is emitted according to the frequency condition:

$$h\nu = \epsilon_{n_1 n_2 n_3} \ldots - \epsilon_{m_1 m_2 m_3} \ldots \ldots \tag{1}$$

where $\epsilon_{n_1 n_2 n_3} \ldots, \epsilon_{m_1 m_2 m_3} \ldots$ are the energies of the atom in the stationary states, and h is Planck's constant.

The first hypothesis we have made use of in the preceding, and we have seen how the stationary states can be found in conditionally periodic systems. The second hypothesis we have seen is supported by Einstein's derivation of Planck's radiation formula § 10).

As a first application of the method of applying these two hypotheses to spectral lines we shall consider the Stark effect, that is, the resolution of a spectral line into components under the influence of an external electric field. The model of an atom used in all of these applications is the Rutherford model, which consists of one or more positive nuclei with electrons circulating about them in orbital motion. It is only in the simplest case where the spectral radiation comes from a single electron in one of the outer orbits that definite results have been obtained. But the results that have recently been obtained by applying the quantum conditions for systems with many degrees of freedom, not only as far as the position of the components is concerned, but also their relative intensities and state of polarization, are in such close agreement with observation that there can be little doubt about the validity of the fundamental hypotheses.

27. The Stark Effect.

The following treatment of the Stark effect is due to Epstein;[1] Sommerfeld[2] and Schwarzschild[3] have also, by somewhat different methods, treated this problem.

Let the charge of the positive nucleus be se and that of the electron $-e$. We assume that a uniform electric force, E, acts along the z-axis. Let r be the distance of the electron from the nucleus, ρ its distance from the z-axis, and φ the angle the plane through the axis containing the electron makes with a fixed plane through the axis. Then the kinetic energy of the electron is:

$$T = \frac{1}{2} m(\dot{z}^2 + \dot{\rho}^2 + \rho^2\dot{\varphi}^2)$$

and the potential energy:

$$V = -\frac{se^2}{r} - eEz$$

where $r^2 = z^2 + \rho^2$.

In order to get coördinates in which the Hamilton-Jacobi equation

[1] *Annalen der Physik*, 50, 1916 (489).

[2] *Ibid.*, 51, 1916 (1).

[3] *Berlin Berichte*, 1916 (548).

may be integrated by separation of variables we shall introduce parabolic coördinates in any meridian plane, defined by:

$$z + i\rho = \frac{1}{2}(\xi + i\eta)^2 \tag{2}$$

From which

$$\left.\begin{aligned} z &= \frac{1}{2}(\xi^2 - \eta^2) \\ r &= \frac{1}{2}(\xi^2 + \eta^2) \end{aligned}\right\} \tag{3}$$

The element of path of the electron is given by:

$$ds^2 = dz^2 + d\rho^2 + \rho^2 d\varphi^2$$

or

$$\begin{aligned} ds^2 &= (dz + id\rho)(dz - id\rho) + \rho^2 d\varphi^2 \\ &= (\xi^2 + \eta^2)(d\xi^2 + d\eta^2) + \xi^2\eta^2 d\varphi^2 \end{aligned}$$

Therefore:

$$T = \frac{1}{2} m(\xi^2 + n^2)\left\{\dot{\xi}^2 + \dot{\eta}^2 + \frac{\xi^2\eta^2}{\xi^2 + \eta^2}\dot{\varphi}^2\right\} \tag{4}$$

$$V = -\frac{4se^2 + eE(\xi^4 - \eta^4)}{2(\xi^2 + \eta^2)} \tag{5}$$

The components of momenta are:

$$\left.\begin{aligned} p_\xi &= \frac{\partial T}{\partial \dot{\xi}} = m(\xi^2 + \eta^2)\dot{\xi} \\ p_\eta &= \frac{\partial T}{\partial \dot{\eta}} = m(\xi^2 + \eta^2)\dot{\eta} \\ p_\phi &= \frac{\partial T}{\partial \dot{\varphi}} = m\xi^2\eta^2\dot{\varphi} \end{aligned}\right\} \tag{6}$$

The Hamilton-Jacobi equation is

$$\frac{1}{2m(\xi^2 + \eta^2)}\left\{\left(\frac{\partial W}{\partial \xi}\right)^2 + \left(\frac{\partial W}{\partial \eta}\right)^2 + \left(\frac{1}{\xi^2} + \frac{1}{\eta^2}\right)\left(\frac{\partial W}{\partial \varphi}\right)^2 \right.$$
$$\left. - 4sme^2 - meE(\xi^4 - \eta^4)\right\} + \alpha_1 = O \tag{7}$$

where α_1 is the negative energy.

φ is a cyclic coördinate; hence

$$p_\phi = \alpha_2 = \text{const.}$$

Separation of the variables is obtained by taking:

$$W = \alpha_2\phi + W_\xi + W_\eta \tag{8}$$

When this is substituted into (7) we get:

$$\left(\frac{\partial W_\xi}{\partial \xi}\right)^2 + \frac{\alpha_2^2}{\xi^2} - 2mse^2 - meE\xi^4 + 2m\alpha_1\xi^2$$
$$= -\left(\frac{\partial W_\eta}{\partial \eta}\right)^2 - \frac{\alpha_2^2}{\eta^2} + 2mse^2 - meE\eta^4 - 2m\alpha_1\eta^2$$

The left-hand side of this equation is a function of ξ only and the right-hand side a function of η only. They are therefore both equal to a constant, α_3. We therefore find:

$$W_\xi = \int d\xi \sqrt{(2mse^2 + \alpha_3) - \frac{\alpha_2^2}{\xi^2} - 2m\alpha_1\xi^2 + meE\xi^4} \qquad (9)$$

$$W_\eta = \int d\eta \sqrt{(2mse^2 - \alpha_3) - \frac{\alpha_2^2}{\eta^2} - 2m\alpha_1\eta^2 - meE\eta^4} \qquad (10)$$

$$W_\phi = \alpha_2\phi \qquad (11)$$

Let us change the variables by the substitution

$$\xi^2 = \xi'$$
$$\eta^2 = \eta'$$

and then write the equations without the accents:

$$W_\xi = \frac{1}{2}\int \frac{d\xi}{\xi} \sqrt{-\alpha_2^2 + (2mse^2 + \alpha_3)\xi - 2m\alpha_1\xi^2 + meE\xi^3} \quad (12)$$

$$W_\eta = \frac{1}{2}\int \frac{d\eta}{\eta} \sqrt{-\alpha_2^2 + (2mse^2 - \alpha_3)\eta - 2m\alpha_1\eta^2 - meE\eta^3} \quad (13)$$

The quantum conditions are now, by IV (1) and (2):

$$2\int_{\xi_1}^{\xi_2} p_\xi d\xi = \int_{\xi_1}^{\xi_2} \frac{d\xi}{\xi} \sqrt{-\alpha_2^2 + (2mse^2 + \alpha_3)\xi - 2m\alpha_1\xi^2 + meE\xi^3} = n_1 h \quad (14)$$

$$2\int_{\eta_1}^{\eta_2} p_\eta d\eta = \int_{\eta_1}^{\eta_2} \frac{d\eta}{\eta} \sqrt{-\alpha_2^2 + (2mse^2 - \alpha_3)\eta - 2m\alpha_1\eta^2 - meF\eta^3} = n_2 h \quad (15)$$

$$\int p_\phi d\varphi = 2\pi\alpha_2 = n_3 h \qquad (16)$$

In these expressions, ξ_1, ξ_2 and η_1, η_2 are the two roots of the corresponding radicals between which the coördinates of the initial position of the electron lie.

We shall now assume that the external field, E, is so small that the force due to it acting on the electron is small compared to the

force arising from the nucleus. Expanding the radicals, and keeping terms of the first order only in E, we get:

$$\int_{\xi_1}^{\xi_2} \frac{d\xi}{\xi} \sqrt{-\alpha_2^2 + (2mse^2 + \alpha_3)\xi - 2m\alpha_1\xi^2}$$

$$+ \frac{meE}{2} \int_{\xi_1}^{\xi_2} \frac{\xi^2 d\xi}{\sqrt{-\alpha_2^2 + (2mse^2 + \alpha_3)\xi - 2m\alpha_1\xi^2}} = n_1 h \qquad (17)$$

$$\int_{\eta_1}^{\eta_2} \frac{d\eta}{\eta} \sqrt{-\alpha_2^2 + (2mse^2 - \alpha_3)\eta - 2m\alpha_1\eta^2}$$

$$- \frac{meE}{2} \int_{\eta_1}^{\eta_2} \frac{\eta^2 d\eta}{\sqrt{-\alpha_2^2 + (2mse^2 - \alpha_3)\eta - 2m\alpha_1\eta^2}} = n_2 h \qquad (18)$$

In these integrals, for ξ_1, ξ_2 and η_1, η_2 we may take the two roots of the quadratics under the radicals and our results will be valid as far as terms in E.

The integrals are all known forms, and we find:

$$-\pi\alpha_2 + \frac{2mse^2 + \alpha_3}{2\sqrt{2m\alpha_1}}\pi + \frac{\pi meE}{64\ m^2\alpha_1^2\sqrt{2m\alpha_1}} \left\{ 3(2mse^2 + \alpha_3)^2 - 8m\alpha_1\alpha_2^2 \right\} = n_1 h \qquad (19)$$

$$-\pi\alpha_2 + \frac{2mse^2 - \alpha_3}{2\sqrt{2m\alpha_1}}\pi - \frac{\pi meE}{64\ m^2\alpha_1^2\sqrt{2m\alpha_1}} \left\{ 3(2mse^2 - \alpha_3)^2 - 8m\alpha_1\alpha_2^2 \right\} = n_2 h \qquad (20)$$

$$2\pi\alpha_2 = n_3 h \qquad (21)$$

Suppose first that $E = o$. Then adding the first two equations we get:

$$\alpha_1 = \frac{2\pi^2 ms^2e^4}{(n_1 + n_2 + n_3)^2h^2} \qquad (22)$$

Subtracting them:

$$\alpha_3 = \frac{2mse^2(n_1 - n_2)}{(n_1 + n_2 + n_3)} \qquad (23)$$

Then using these values of α_1 and α_3 in the terms containing E, we get, as far as terms of the first degree in E:

$$\alpha_1 = \frac{2ms^2e^4\pi^2}{(n_1 + n_2 + n_3)^2h^2} + \frac{3}{8}\,\frac{Eh^2(n_1 - n_2)(n_1 + n_2 + n_3)}{\pi^2 mse} \qquad (24)$$

Let now n_1 n_2, n_3 be the three integers characterizing one sta-

tionary state and m_1, m_2, m_3 the three integers characterizing another stationary state. Since α_1 is the (negative) energy, we have by Bohr's frequency condition (1)

$$\nu = \frac{2\pi^2 s^2 m e^4}{h^3 c}\left\{\frac{1}{(n_1+n_2+n_3)^2} - \frac{1}{(m_1+m_2+m_3)^2}\right\} + \frac{3}{8}\frac{Eh}{\pi^2 msec}\left\{\begin{matrix}(n_1-n_2)(n_1+n_2+n_3) \\ -(m_1-m_2)(m_1+m_2+m_3)\end{matrix}\right\} \quad (25)$$

c, the velocity of light, is introduced so that ν may represent, as is customary in spectroscopy, the reciprocal of the wave-length. Writing:

$$\nu = \nu_0 + \Delta\nu$$

where

$$\nu_0 = N\left\{\frac{1}{(n_1+n_2+n_3)^2} - \frac{1}{(m_1+m_2+m_3)^2}\right\} \quad (26)$$

and N is the Rydberg constant:

$$N = \frac{2\pi^2 m s^2 e^4}{h^3 c}. \quad (27)$$

$\Delta\nu$ is the frequency change due to the electric field:

$$\Delta\nu = -\frac{3}{8}\frac{h}{\pi^2 msec}EZ \quad (28)$$

where

$$Z = (m_1-m_2)(m_1+m_2+m_3) - (n_1-n_2)(n_1+n_2+n_3) \quad (29)$$

ν_0 is the frequency (reciprocal of wave-length) when no electric field acts. In terms of the wave-length the displacement due to the electric field is:

$$\Delta\lambda = \frac{3}{8}\frac{h\lambda^2}{\pi^2 msec}EZ \quad (30)$$

(26) is the Balmer series for hydrogen if we put $s = 1$, corresponding to a single nucleus of charge $+e$, and take:

$$n_1 + n_2 + n_3 = 2$$

$$m_1 + m_2 + m_3 = 3, 4, 5, \ldots\ldots$$

We notice in the absence of the electric field the system is degenerate (§ 15); for although there are three degrees of freedom the three quantum numbers enter in a single linear combination so that the whole motion of the system is periodic. We notice further that the displacement of the spectral lines under the influence of an electric field is proportional to the external electric

force, which is what Stark found. This justifies our procedure in neglecting higher powers of E than the first. And since for any value of Z, by combining the integers properly, it is always possible to get an equal opposite value, the displacements of the spectral lines will be symmetrical with respect to the undisplaced lines. This also agrees with Stark's observations.

28. Sommerfeld's Selective Principle.

For any line, $n_1 + n_2 + n_3$ and $m_1 + m_2 + m_3$ are fixed integers. With no other restrictions on the possible values of these six integers there would be more different values of Z than correspond to observation. Sommerfeld has accordingly stated a principle of selection which limits the choice of these integers. According to this principle:

$$m_1 + m_2 + m_3 > n_1 + n_2 + n_3$$

and

$$m_1 \geqq n_1$$
$$m_2 \geqq n_2$$
$$m_3 \geqq n_3$$

Moreover, m_3 and n_3 arise from the third quantum condition (21); zero values of these integers therefore correspond to a motion in which the momentum of the electron about the axis is zero. It seems reasonable, therefore, to exclude zero values for the integers n_3 and m_3.

We should rather expect that the greater the number of possible ways of getting a given Z, the more intense the corresponding component would be. In a general way this is found to be verified by Stark's observations. Furthermore, Epstein found, from Stark's observations, that for $m_3 - n_3$ even, the corresponding component is polarized so that the electric vector is parallel to the external field; and for $m_3 - n_3$ odd, the electric vector is perpendicular to the field.

It is difficult to give a satisfactory reason for Sommerfeld's selective principle and for Epstein's polarization rule. Bohr has recently obtained results of very great importance with respect to the intensity and state of polarization of the several components by following quite a different procedure, and his methods will be described later. And so for the present we shall merely show how Sommerfeld's selective principle, combined with (30), gives the position of the components in the Stark effect in hydrogen.

29. Numerical Values.

With the following values of the constants:

$$e = 4.774 \ 10^{10}$$

$$\frac{e}{m} = 5.301 \ 10^{17}$$

$$h = 6.545 \ 10^{27}$$

(27) gives:

$$N = 1.098 \ 10^{5}$$

while spectroscopic measurements give:

$$N = 1.09675 \ 10^{5}$$

Using these values in (30) and measuring E in volts per centimeter:

$$\Delta\lambda = 6.43 \ 10^{5} \ \lambda^2 EZ$$

Stark used an electric force of 104,000 volts per centimeter; with this value, we get for the first four lines in the Balmer series for hydrogen:

	$n_1+n_2+n_3$	$m_1+m_2+m_3$	λ	$\Delta\lambda$
H_α	2	3	6562.8 Å.	2.88 Z Å.
H_β	2	4	4861.3	1.58 Z
H_γ	2	5	4340.5	1.26 Z
H_δ	2	6	4101.7	1.13 Z

The following tables give the results of Stark's measurements in these four hydrogen lines, together with the computed displacements. The first column shows how the transition may be made from m_1, m_2, m_3 to n_1, n_2, n_3. The second column gives the value of Z from (29), the third the computed displacement from (30), and the last column the observed displacement. Transitions which result in negative values of Z are omitted as they correspond to the symmetrically situated components; also multiple transitions, leading to the same values of Z are omitted. Transitions which violate Sommerfeld's selective principle, or the rule that neither m_3 nor n_3 shall be zero, are marked with an asterisk. Each table is divided into two groups, the first containing those transitions for which m_3-n_3 is even, and the second those for which m_3-n_3 is odd. The former correspond to polarization such that the electric vector is parallel to the external field, and the latter, perpendicular to the field.

$H\alpha$ 6562.8 Å.

	Transition	Z	$\Delta\lambda$ Calc.	$\Delta\lambda$ Obs.
Parallel	111 ⟶ 011	2	5.8 Å	6.2 Å
	102 ⟶ 002	3	8.6	8.8
	201 ⟶ 101	4	11.5	11.5
Perp.	003 ⟶ 002	0	0	0
	102 ⟶ 101	1	2.9	2.6

	Transition	Z	$\Delta\lambda$ Calc.	$\Delta\lambda$ Obs.
		H_β 4861.3Å.		
Parallel	112 → 002	0	0	0
	211 → 101	2	3.2	3.3
	220 → 020*	4	6.3	6.7
	211 → 011	6	9.5	10.0
	202 → 002	8	12.6	13.2
	301 → 101	10	15.8	16.4
	301 → 110*	12	19.0	19.4
Perpendicular	112 → 011	2	3.2	3.4
	103 → 002	4	6.3	6.6
	202 → 101	6	9.5	9.7
	202 → 110	8	12.6	13.2
	202 → 011	10	15.8	16.4
	301 → 002*	12	19.0	19.3
		H_γ 4340.5 Å.		
Parallel	221 → 011	2	2.5	2.7
	212 → 002	5	6.3	6.6
	311 → 101	8	9.7	10.6
	311 → 011	12	15.1	15.9
	320 → 002	15	18.9	19.9
	401 → 101	18	22.3	23.9
	401 → 011	22	27.7	?
Perpendicular	113 → 002	0	0	0
	212 → 101	3	3.8	3.9
	212 → 011	7	8.6	9.7
	203 → 002	10	12.6	13.3
	302 → 101	13	16.4	17.3
	302 → 011	17	21.4	22.8
	401 → 002*	20	25.2	26.3
		H_δ 4101.7 Å.		
Parallel	222 → 002	0	0	0
	321 → 101	4	4.5	5.2
	321 → 011	8	9.0	9.6
	312 → 002	12	13.6	14.4
	411 → 101	16	18.2	19.6
	411 → 011	20	22.6	24.2
	402 → 002	24	27.1	28.6
	501 → 101	28	31.6	33.4
	501 → 011	32	36.2	37.5
Perpendicular	222 → 011	2	2.3	2.4
	213 → 002	6	6.8	7.4
	312 → 101	10	11.3	11.9
	312 → 011	14	16.7	17.2
	303 → 002	18	20.3	21.3
	402 → 101	22	24.9	25.8
	402 → 011	26	29.4	30.4
	501 → 002*	30	33.9	34.8

30. Series of the Rydberg type.

The Balmer series (26) is the simplest type of a spectral series

and it is important to consider the possibility of obtaining more general types of series. Tank[1] and Silberstein[2] have considered questions of this kind. If we assume an atom of the Rutherford model, formed of a positive nucleus with electrons circulating about it in orbital motion, we may divide the electrons into two classes: the constituent electrons whose orbits are near the nucleus and lie in parallel planes, and the series electrons at a greater distance from the nucleus; it is to the latter electrons that the series emission is due in Bohr's theory. It may be shown that to a certain approximation the forces acting on a series electron arising from the nucleus and the constituent electrons may be replaced by forces arising from two point charges at a small distance apart. The problem therefore is reduced to that of finding the motion of an electron about two centers of force. This is a familiar astronomical problem and is most easily solved in elliptic coördinates.

Assume that there are two positive charges, E' and E''; let $2b$ be the distance between these charges, and r' and r'' the distances of the electron from them. Introduce elliptic coördinates, λ, μ, defined by:

$$\left.\begin{aligned} \lambda &= \frac{1}{2}(r' + r'') \\ \mu &= \frac{1}{2}(r' - r'') \end{aligned}\right\} \quad (31)$$

Take an origin at the mid-point of the two charges E', E'', with cylindrical coördinates, z, ρ, φ, the two charges being on the z-axis. Then λ = const. is an ellipse in any z-ρ plane, having the two charges as foci, and λ for its semi-major axis. μ = const. is a confocal hyperbola with μ for its semi-major axis. The equations of these curves are:

$$\frac{Z^2}{\lambda^2} + \frac{\rho^2}{\lambda^2 - b^2} = 1$$

$$\frac{Z^2}{\mu^2} - \frac{\rho^2}{b^2 - \mu^2} = 1$$

The element of arc in cylindrical coördinates is given by:

$$ds^2 = dz^2 + d\rho^2 + \rho^2 d\varphi^2$$

In elliptic coördinates we find:

$$ds^2 = \frac{\lambda^2 - \mu^2}{\lambda^2 - b^2}\,d\lambda^2 + \frac{\lambda^2 - \mu^2}{b^2 - \mu^2}\,d\mu^2 + \frac{(\lambda^2 - b^2)(b^2 - \mu^2)}{b^2}$$

[1] *Annalen der Physik*, **59**, 1919 (293).

[2] *Phil. Mag.*, January, 1920.

The kinetic energy of the electron is therefore:

$$T=\frac{1}{2} m \left(\frac{ds}{dt}\right)^2 = \frac{1}{2} m \left\{ \frac{\lambda^2 - \mu^2}{\lambda^2 - b^2}\dot{\lambda}^2 + \frac{\lambda^2 - \mu^2}{b^2 - \mu^2}\dot{\mu}^2 + \frac{(\lambda - b^2)(b^2 - \mu^2)}{b^2}\dot{\varphi}^2 \right\}$$

and the potential energy:

$$V = -\frac{eE'}{r'} - \frac{eE''}{r''} \text{ or: } V = -\frac{eE'}{\lambda + \mu} - \frac{eE''}{\lambda - \mu}$$

The components of momenta are:

$$p_\lambda = \frac{\partial T}{\partial \dot{\lambda}} = m \frac{\lambda^2 - \mu^2}{\lambda^2 - b^2}\dot{\lambda}$$

$$p_\mu = \frac{\partial T}{\partial \dot{\mu}} = m \frac{\lambda^2 - \mu^2}{b^2 - \mu^2}\dot{\mu}$$

$$p_\phi = \frac{\partial T}{\partial \dot{\varphi}} = m \frac{(\lambda^2 - b^2)(b^2 - \mu^2)}{b^2}\dot{\varphi}$$

The Hamilton-Jacobi equation is:

$$\frac{\lambda^2 - b^2}{\lambda^2 - \mu^2}\left(\frac{\partial W}{\partial \lambda}\right)^2 + \frac{b^2 - \mu^2}{\lambda^2 - \mu^2}\left(\frac{\partial W}{\partial \mu}\right)^2 + \frac{b^2}{(\lambda^2 - b^2)(b^2 - \mu^2)}\left(\frac{\partial W}{\partial \varphi}\right)^2$$
$$- \frac{2me}{\lambda^2 - \mu^2}\left\{ E'(\lambda - \mu) + E''(\lambda + \mu) \right\} + 2m\alpha_1 = 0 \tag{32}$$

where α_1 is the constant (negative) energy.

φ being a cyclic coördinate, we assume:

$$W = W_\lambda + W\mu + \alpha_3\varphi \tag{33}$$

and we find:

$$\frac{\partial W_\lambda}{\partial \lambda} = p_\lambda = \frac{1}{\lambda^2 - b^2}$$
$$\sqrt{(\lambda^2 - b^2)\left\{-2m\alpha_1\lambda^2 + 2me(E' + E'')\lambda - \alpha_3\right\} - \alpha_2^2\lambda^2} \tag{34}$$

$$\frac{\partial W_\mu}{\partial \mu} = p_\mu = \frac{1}{b^2 - \mu^2}$$
$$\sqrt{(\mu^2 - b^2)\left\{-2m\alpha_1\mu^2 + me(E' - E'')\mu - \alpha_3\right\} - \alpha_2^2\mu^2} \tag{35}$$

$$\frac{\partial W_\phi}{\partial \varphi} = p_\phi = \alpha_2 \tag{36}$$

The quantum conditions are now:

$$2\int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^2 - b^2} \sqrt{(\lambda^2 - b^2)\left\{-2m\alpha_1\lambda^2 + 2me(E' + E'')\lambda - \alpha_3\right\} - \alpha_2^2\lambda^2}$$
$$= n_1 h \tag{37}$$

$$2\int_{\mu_1}^{\mu_2} \frac{d\mu}{b^2 - \mu^2} \sqrt{(\mu^2 - b^2)\{-2m\alpha_1\mu^2 + 2me(E' - E'')\mu - \alpha_3\} - \alpha_2^2\mu^2}$$

$$= n_2 h \quad (38)$$

$$\int_0^{2\pi} \alpha_2 d\varphi = 2\pi\alpha_2 = n_3 h \quad (39)$$

In the first of these integrals, λ is of the order of magnitude of the distance of the electron from the origin which we assume large compared to b. We shall therefore expand the radical in powers of λ/b, as far as terms in b^2. This gives for the first integral:

$$2\int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda} \sqrt{-2m\alpha_1\lambda^2 + 2me(E' + E'')\lambda - (\alpha_3 + \alpha_2^2)}$$

$$+ b^2\int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^3} \sqrt{-2m\alpha_1\lambda^2 + 2me(E' + E'')\lambda - (\alpha_3 + \alpha_2^2)} \quad (40)$$

$$- b^2\alpha_2^2\int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^3} \frac{1}{\sqrt{-2m\alpha_1\lambda^2 + 2me(E' + E'')\lambda - (\alpha^3 - \alpha_2^2)}} = n_1 h$$

To this approximation, for the limits λ_1, λ_2, we may take the two roots of the quadratic under the radical.

In (38) put

$$\mu = bx$$

Then x will be o in the equatorial plane, and will always be less than unity. Expanding this equation as far as terms in b^2, we get:

$$2\int_{x_1}^{x_2} \frac{dx\sqrt{\alpha_3 - (\alpha_3 + \alpha_2^2)x^2}}{1 - x^2} - 2meb(E' - E'')\int_{x_1}^{x_2} \frac{xdx}{\sqrt{\alpha_3 - (\alpha_3 + \alpha_2^2)x^2}} \quad (41)$$

$$+ 2m\alpha_1 b^2\int_{x_1}^{x_2} \frac{x^2 d\gamma}{\sqrt{\alpha_3 + (\alpha_3 + \alpha_2^2)x^2}} - m^2e^2b^2(E' - E'')^2\int_{x_1}^{x_2} \frac{x^2(1 - x^2)dx}{\{\alpha_3 - (\alpha_3 + \alpha_2^2)x^2\}^{\frac{3}{2}}}$$

$$= n_2 h$$

All the integrals are known forms and can be easily solved. The last one, however, becomes indeterminate when the limits are put in; it may be written:

$$\int_{x_1}^{x_1} \frac{x^2(1 - x^2)dx}{\left\{\alpha_3 - (\alpha_3 + \alpha_2^2)x^2\right\}^{\frac{3}{2}}} = \frac{1}{(\alpha_3 + \alpha_2^2)^{\frac{3}{2}}} \int_{-x_1}^{+x_1} \frac{x^2(1 - x^2)dx}{(x_1^2 - x^2)^{\frac{3}{2}}}$$

$$= -\frac{1}{(\alpha_3 + \alpha_2^2)^{\frac{3}{2}}} \frac{d}{dx_1} x_1 \int_{-x_1}^{+x_1} \frac{1 - x^2}{\sqrt{x_1^2 - x^2}} dx$$

$$= \frac{\pi}{(\alpha_3 + \alpha_2^2)^{\frac{3}{2}}} \left\{ \frac{3}{2} \frac{\alpha_3}{\alpha_3 + \alpha_2^2} - 1 \right\}$$

The quantum conditions now become:

$$\frac{2me\pi(E' + E'')}{\sqrt{2m\alpha_1}} - 2\pi\sqrt{\alpha_2 + \alpha_2^2} + \frac{b^2\pi}{\sqrt{\alpha_3 + \alpha_2^2}} \left\{ \frac{m^2e^2(E' + E'')^2}{2(\alpha_3 + \alpha_2^2)} - m\alpha_1 \right\}$$
$$+ \frac{b^2\pi\alpha_2^2}{\sqrt{\alpha_3 + \alpha_2^2}} \left\{ \frac{m\alpha_1}{\alpha_3 + \alpha_2^2} - \frac{3}{2} \frac{m^2e^2(E' + E'')^2}{(\alpha_3 + \alpha_2^2)^2} \right\} = n_1h \tag{42}$$

$$2\pi\sqrt{\alpha_3 + \alpha_2^2} - 2\pi\alpha_2 + \frac{b^2\pi m\alpha_1\alpha_3}{(\alpha_3 + \alpha_2^2)^{\frac{3}{2}}}$$
$$- \frac{b^2m^2e^2\pi(E' - E'')^2}{(\alpha_3 + \alpha_2^2)^{\frac{3}{2}}} \left\{ \frac{3}{2} \frac{\alpha_3}{\alpha_3 + \alpha_2^2} - 1 \right\} = n_2h \tag{43}$$

$$2\pi\alpha_2 = n_3h \tag{44}$$

If we take $b = 0$, we get at once:

$$\alpha_1 = \frac{2\pi^2me^2(E' + E'')^2}{(n_1 + n_2 + n_3)^2h^2} \tag{45}$$

$$\alpha_3 + \alpha_2^2 = \frac{(n_2 + n_3)^2h^2}{4\pi^2} \tag{46}$$

$$\alpha_3 = \frac{n_2(n_2 + 2n_3)h^2}{4\pi^2} \tag{47}$$

Our expression for α_1, the negative energy, is the same as (22) if we take $E' + E'' = e$, and put $\quad = 1$ in (22), corresponding to a single nucleus. We thus get an illustration of the property of degenerate systems that separation of the variables is possible in more than one system of coördinates (§ 16).

The quantum conditions (42) and (43) may be rewritten:

$$\frac{2me\pi(E' + E'')}{\sqrt{2m\alpha_1}} - 2\pi\sqrt{\alpha_3 + \alpha_2^2} + \frac{b^2\pi m^2e^2(E' + E'')^2(\alpha_3 - 2\alpha_2^2)}{2(\alpha_3 + \alpha_2^2)^{\frac{5}{2}}}$$
$$- \frac{b^2\pi m\alpha_1\alpha_3}{(\alpha_3 + \alpha_2^2)^{\frac{3}{2}}} = n_1h$$

$$2\pi\sqrt{\alpha_3 + \alpha_2^2} - \frac{b^2\pi m^2e^2(E' - E'')^2(\alpha_3 - 2\alpha_2^2)}{(\alpha_3 + \alpha_2^2)^{\frac{5}{2}}} + \frac{b^2\pi m\alpha_1\alpha_3}{(\alpha_3 + \alpha_2^2)^{\frac{3}{2}}} = (n_2 + n_3)\,h$$

Adding these equations:

$$\frac{2me\pi(E' + E'')}{\sqrt{2m\alpha_1}} + \frac{2b^2\pi m^2e^2(\alpha_3 - 2\alpha_2^2)E'E''}{(\alpha_3 + \alpha_2^2)^{\frac{5}{2}}} = (n_1 + n_2 + n_3)h$$

In the term containing b^2 substitute from (46) and (47) the values corresponding to $b = 0$.

$$\frac{2me\pi(E' + E'')}{\sqrt{2m\alpha_1}} = (n_1 + n_2 + n_3)h + \frac{16b^2\pi^4m^2e^2E'E''(2n_3^2 - n_2^2 - 2n_2n_3)}{h^3(n_2 + n_3)^5(n_1 + n_2 + n_3)}$$

Solving for α_1, as far as terms in b^2:

$$\alpha_1 = \frac{2me^2\pi^2(E' + E'')^2}{(n_1 + n_2 + n_3)^2h^2}\left\{1 - \frac{2\,\Delta n}{n_1 + n_2 + n_3}\right\}$$

where

$$\Delta n = \frac{16b^2\pi^4m^2e^2E'E''(2n_3^2 - n_2^2 - 2n_2n_3)}{h^4(n_2 + n_3)^5}$$

and this may also be written, to the same approximation:

$$\alpha_1 = \frac{2me^2\pi^2(E' + E'')}{(n_1 + n_2 + n_3 + \Delta n)^2h^2}$$

Applying now Bohr's frequency condition (1) we see that we can get series of the general Rydberg type:

$$\nu = \nu_0 - \frac{N_0}{(n + \Delta n)^2}$$

where Δn may be positive or negative, and n is any integer $(n_1 + n_2 + n_3)$.

31. Band Spectra.

Schwarzschild has made an interesting application of the quantum theory to band spectra. Band spectra are generally regarded as having their origin in the molecules, and line spectra in the atoms. We have previously found (§ 20 (11)) that regarding a molecule as a rigid body symmetrical about an axis, its energy in the stationary states was given by:

$$\epsilon_n = \frac{h^2n^2}{8\pi^2I}$$

where n is any integer, and I the moment of inertia about an axis perpendicular to the axis of symmetry. Let us now suppose that electrons circulate about the molecule and disregard, as a first ap-

proximation, any mutual influence of the molecule and electrons. Then the total energy of the system in the nth stationary state will be

$$E_n + \frac{h^2n^2}{8\pi^2 I}$$

where E_n is the energy of the electrons. In the mth state the energy will be

$$E_m + \frac{h^2m^2}{8\pi^2 I}$$

By Bohr's frequency condition (1):

$$\nu = \frac{E_m - E_n}{h} - \frac{hn^2}{8\pi^2 I} + \frac{hm^2}{8\pi^2 I} \tag{48}$$

which may be written, if n is fixed and m takes integral values:

$$\nu = a + bm^2 \tag{49}$$

where:

$$b = \frac{h}{8\pi^2 I} \tag{50}$$

(49) is Deslandre's formula for the lines in a band spectrum; from the known values of the constant b, I may be determined by (50). Schwarzschild gives the following results:

	Wave-length of Head of Band	I
Oxygen	6277 Å.	$8.0 \; 10^{-39}$
Oxygen	6868	$10.0 \; 10^{-39}$
Oxygen	7594	$14.0 \; 10^{-39}$
Mercury	4215	$1.8 \; 10^{-39}$
Nitrogen	3883	$40.0 \; 10^{-32}$
Nitrogen	3577	$14.0 \; 10^{-39}$
Water	3200	$0.3 \; 10^{-39}$

The values of the moments of inertia of the various molecules found in this way are of about the order of magnitude to be expected. In the case of water vapor, for example, the moment of inertia of the water molecule comes out about twelve times that of a hydrogen molecule as determined from Bohr's model of the hydrogen molecule or from the behavior of the specific heat at low temperatures (§ 21).

VIII. INTENSITY AND POLARIZATION OF SPECTRAL LINES

32. In the former chapter the method of applying Bohr's two principles to the determination of the frequencies of radiation from atoms of the hydrogen type, considered as conditionally periodic systems, has been illustrated, and the results have been

found to be in close agreement with observation. In order, however, to limit the number of frequencies in the Stark effect to that actually observed, and to give an account of the state of polarization of the various components, it was necessary to make use of more or less arbitrary rules. As for the relative intensities of the different components, all that could be said was that the intensity of a component would be expected to be proportional to the number of possible transitions, which give rise to that component. In a case like that of the $H\alpha$ line there is only one possible transition for each component and, therefore, according to this principle, all the components should be of equal intensity.

A memoir of great importance for the whole theory of the application of the quantum theory to line spectra is now in course of publication by Bohr.[1] In the two parts that have already appeared a critical review of the quantum theory, as far as its application to line spectra is concerned, is given, and a remarkable extension of the theory is made by means of which it is possible to determine the intensity and state of polarization of all the components into which a spectral line is resolved under the action of an electric field (Stark effect), or a magnetic field (Zeeman effect). The fine structure of the lines of the hydrogen and helium spectra to account for which the change in mass of an electron according to the principle of relativity has to be considered, is another important problem which Bohr has discussed in detail. The results which have been published so far relate only to atoms of the simple hydrogen type. Application of the new methods to other atoms is promised in the remaining parts of Bohr's memoir which may be looked forward to with great interest.

In a valuable memoir by Kramers,[2] Bohr's methods are carried out in detail so as to obtain numerical results for the purpose of testing the validity of these methods. In order to illustrate the principles upon which these methods are based, one of the problems, that of the intensity of the components in the Stark effect, solved by Kramers, will be given here.

33. Dynamical Frequencies and Bohr's Frequency Principle.

We have seen (§ 15) that in a conditionally periodic system the generalized coördinates, q_1, q_2, . . ., are periodic functions of the

[1] *D. Kgl. Danske Vidensk. Selsk. Skrifter, Naturvidensk og Mathem.* Afd. 8. Raekke, IV, 1918.

[2] *Memoires de l' Academie Royale des Sciences et des Lettres de Danemark*, Copenhague, Section des Sciences, 8me serie, t. III, No. 3, 1919.

angle variables, w_1, w_2, ..., with the period 2π. The actual displacements of the system, x_1, x_2, ... being functions of the generalized coördinates are also, therefore, periodic functions of the angle variables with the period 2π. Such functions may be developed by the generalized Fourier's theorem for many variables:

$$x = \sum A_{\tau_1\tau_2}\ldots e^{i(\tau_1 w_1 + \tau_2 w_2 + \ldots .)} \tag{1}$$

where the summation is a multiple one, over all the positive and negative integers, τ_1, τ_2, ... The coefficients in this expansion are determined by:

$$A_{\tau_1\tau_2}\ldots = \frac{1}{(2\pi)^f}\int_0^{2\pi}\ldots f\int_0^{2\pi} x(w_1 w_2\ldots)e^{-i(\tau_1 w_1 + \tau_2 w_2 + \ldots)}\,dw_1 dw_2\ldots \tag{2}$$

The angle variables are given by (III, (21))

$$w_k = \omega_k t + \delta_k$$

where ω_k is the "mean motion" corresponding to w_k. Using this in (1) we have:

$$x = \sum A_{\tau_1\tau_2\ldots} e^{i(\tau_1\omega_1 + \tau_2\omega_2 + \ldots)t + \Sigma\tau_k\delta_k} \tag{3}$$

Now, according to ordinary dynamics, we should expect the frequency of radiation emitted by such a system to be given by:

$$\nu = \frac{\omega}{2\pi} = \frac{1}{2\pi}(\tau_1\omega_1 + \tau_2\omega_2 + \ldots .) \tag{4}$$

where τ_1, τ_2, . . . are any integers.

The mean motions are determined by (III (40)).

$$\omega_k = 2\pi\frac{\partial H}{\partial I_k} \tag{5}$$

where H is the whole energy expressed in terms of I_1, I_2, . . . and

$$I_k = 2\int_{a_k}^{b_k} p_k dq_k$$

Consider now two different states of the system which differ but little from each other. We may write the difference of the energy in the two states:

$$H(I_1 + \delta I_1, I_2 + \delta I_2, \ldots) - H(I_1, I_2, \ldots .) = \sum\frac{\partial H}{\partial I_k}\delta I_k = \frac{1}{2\pi}\sum\omega_k\delta I_k \tag{6}$$

The preceding is all based on ordinary dynamical principles.

The special quantum hypothesis is that the I's take the definite values, in the stationary states:

$$I_k = n_k h \tag{7}$$

where the n's are integers, and h is Planck's constant. If now the integers which define the stationary states are large numbers then the difference in the values of the I's for two neighboring states will be small compared to their values for either of the states. In this case we will have, from (7),

$$\delta I^k = (n_k'' - n_k')h = \tau_k h$$

and (6) may then be written:

$$\epsilon' - \epsilon'' = \frac{h}{2\pi} \sum \omega_k \tau_k$$

and by comparing with (4) we have:

$$\epsilon' - \epsilon'' = h\nu$$

where ϵ' and ϵ'' are the energies corresponding to the two states. The last formula expresses Bohr's frequency principle. In other words, in the limit of long wave-lengths, the frequencies of vibration determined by the quantum theory agree with the frequencies to be expected from ordinary dynamical theory. This is a result of great importance, for in the region of long wave-lengths it is known that Planck's radiation formula approaches the Rayleigh-Jeans formula which is based on ordinary dynamics.

If the frequencies were determined by (4) from ordinary dynamical principles we should expect the intensity of the radiation of any frequency to be proportional to the square of the amplitude of the corresponding term in the Fourier expansion (3). In particular, if the displacement in any direction is expressed by means of such an expansion, and if the amplitude corresponding to any frequency is o, we should expect the radiation to be polarized in a perpendicular direction. The assumption that Bohr makes, now, is that although the frequencies cannot be determined by ordinary dynamics, yet the intensities will be measured by the squares of the amplitudes of the corresponding terms in the Fourier expansion. Kramers has shown that this principle accounts for the polarization of the several components in the Stark effect in hydrogen. As for the relative intensities, it must be remembered that each frequency is determined by two states, the initial state and the final state. Kramers has shown that a very good representation of the relative intensities is obtained by taking the sum

of the squares of the amplitudes corresponding to the two states defining the frequency. Without further knowledge of the mechanism of radiation it is impossible to say just how the intensity depends upon the amplitudes, and the most reasonable assumption is that it is proportional to the mean of the squares of the two amplitudes.

34. Intensity of the Components in the Stark Effect in hydrogen.

In order to illustrate the application of these ideas we shall give the calculation, following Kramers, of the relative intensities of the components in the Stark effect in hydrogen. For full details of the principles underlying the method and a full discussion of the results, reference must be made to the memoirs of Bohr and of Kramers, referred to above.

We have already obtained (§ 27) the solution of the Hamilton-Jacobi equation in parabolic coördinates in which this equation can be integrated by the method of separation of the variables. In this solution, instead of the three integration constants α_1, α_2, α_3, we must introduce the values I_1, I_2, I_3. As we are now concerned only with the problem of determining the relative intensities we may, as a sufficient approximation, use the values of the integration constants for a zero external field. Remembering that

$$I_k = n_k\, h$$

we find from VII (22), (16), (23):

$$\alpha_1 = \frac{2ms^2e^4\pi^2}{I^2} \tag{8}$$

$$\alpha_2 = \frac{I_3}{2\pi} \tag{9}$$

$$\alpha_3 = \frac{2mse^2(I_1 - I_2)}{I} \tag{10}$$

where we have put:

$$I = I_1 + I_2 + I_3 \tag{11}$$

From VII (14), (15), (16), we then get:

$$2\pi W = I_3\phi + \frac{1}{2}\int \frac{d\xi}{\xi}\sqrt{-I_3^2 + 2\,\frac{2I_1 + I_3}{\sigma I}\,\xi - \frac{\xi^2}{\sigma^2 I^2}}$$
$$+ \frac{1}{2}\int \frac{d\eta}{\eta}\sqrt{-I_3^2 + 2\,\frac{2I_2 + I_3}{\sigma I}\,\eta - \frac{\eta^2}{\sigma^2 I^2}}$$

where we have put:

$$\sigma = \frac{1}{4\pi^2 se^2 m} \tag{12}$$

The angle variables, being given by:

$$w_1 = 2\pi \frac{\partial W}{\partial I_1},\ w_2 = 2\pi \frac{\partial W}{\partial I_2},\ w_3 = 2\pi \frac{\partial W}{\partial I_3}$$

are:

$$\begin{aligned} w_1 = \frac{1}{2\sigma I^2} \int \frac{d\xi}{\xi} \frac{\sigma I(2I_2 + I_3)\xi + \xi^2}{\sqrt{\sigma^2 I^2 I_3^2 + 2\sigma I(2I_1 + I_3)\xi - \xi^2}} \\ + \frac{1}{2\sigma I^2} \int \frac{d\eta}{\eta} \frac{-\sigma I(2I_2 + I_3)\eta + \eta^2}{\sqrt{\sigma^2 I^2 I_3^2 + 2\sigma I(2I_2 + I_3)\eta - \eta^2}} \end{aligned} \tag{13}$$

$$\begin{aligned} w_2 = \frac{1}{2\sigma I^2} \int \frac{d\xi}{\xi} \frac{\sigma I(2I_1 + I_3)\xi + \xi^2}{\sqrt{-\sigma^2 I^2 I_3^2 + 2\sigma I(2I_1 + I_3)\xi - \xi^2}} \\ + \frac{1}{2\sigma I^2} \int \frac{d\eta}{\eta} \frac{\sigma I(2I_1 + I_3)\eta + \eta^2}{\sqrt{-\sigma^2 I^2 I_3^2 + 2\sigma I(2I_2 + I_3)\eta - \eta^2}} \end{aligned} \tag{14}$$

$$\begin{aligned} w_3 = \frac{1}{2\sigma I^2} \int \frac{d\xi}{\xi} \frac{-\sigma^2 I_3 I^3 + \sigma I(I_2 - I_1)\xi + \xi^2}{\sqrt{-\sigma^2 I^2 I_3^2 + 2\sigma I(2I_1 + I_3)\xi - \xi^2}} \\ + \frac{1}{2\sigma I^2} \int \frac{d\eta}{\eta} \frac{-\sigma^2 I_3 I^3 + \sigma I(I_1 - I_2)\eta + \eta^2}{\sqrt{-\sigma^2 I^2 I_3^2 + 2\sigma I(2I_2 + I_3)\eta - \eta^2}} + \varphi \end{aligned} \tag{15}$$

The integrations may be most easily carried out by using the abbreviations:

$$\left.\begin{aligned} M_1 &= \sigma I(2I_1 + I_3) & L_1 &= 2\sigma I\sqrt{I_1^2 + I_3 I_1} \\ M_2 &= \sigma I(2I_2 + I_3) & L_2 &= 2\sigma I\sqrt{I_2^2 + I_3 I_2} \\ \sigma_1 &= \frac{L_1}{2\sigma I^2} & \sigma_2 &= \frac{L_2}{2\sigma I^2} \end{aligned}\right\} \tag{16}$$

and making the substitution:

$$\left.\begin{aligned} \xi &= M_1 + L_1 \cos\psi \\ \eta &= M_2 + L_2 \cos\chi \end{aligned}\right\} \tag{17}$$

so that:

$$\left.\begin{aligned} \frac{d\xi}{\sqrt{-\sigma^2 I^2 I_3^2 + 2\sigma I(2I_1 + I_3)\xi - \xi^2}} &= d\psi \\ \frac{d\eta}{\sqrt{-\sigma^2 I^2 I_3^2 + 2\sigma I(2I_2 + I_3)\eta - \eta^2}} &= d\chi \end{aligned}\right\} \tag{18}$$

The integrals for w_1 and w_2 can now be written immediately, and we have:

$$w_1 = \psi + \sigma_1 \sin\psi + \sigma_2 \sin\chi + \pi \tag{19}$$

$$w_2 = \chi + \sigma_1 \sin\psi + \sigma_2 \sin\chi + \pi \tag{20}$$

The arbitrary constant, π, has been added for future convenience. w_1 and w_2 being angle variables any constants added to them can of course have no effect on the final result.

It will be found convenient later to express the first of the integrals in the expression for w_3 in the logarithmic form, and we can write:

$$w_3 = \varphi + \frac{1}{2}(\psi + \chi) + \pi \tag{21}$$
$$+ i \log \frac{\left\{(M_1 + L_1)\cos\frac{\psi}{2} + \iota\sigma I_1 I_3 \sin\frac{\psi}{2}\right\}\left\{(M_2 + L_2)\cos\frac{\chi}{2} + \iota\sigma I_1 I_3 \sin\frac{\chi}{2}\right\}}{\sqrt{(M_1 + L_1)(M_2 + L_1)}\quad\sqrt{(M_1 + L_1\cos\psi)\,(M_1 + L_2\cos\chi)}}$$

The coördinate of the electron along the axis, z, is given, in terms of the parabolic coördinates we are using by:

$$z = \frac{1}{2}(\xi - \eta)$$

We see ξ and η, and therefore z, are functions of w_1 and w_2 only. We can therefore expand z in a series (1)

$$z = \sum A_{\tau_1\tau_2} e^{i(\tau_1 w_1 + \tau_2 w_2)}$$

where the summation is over all positive and negative integers, τ_1 and τ_2. The coefficients in this expansion are given by (2):

$$A_{\tau_1\tau_2} = \frac{1}{4\pi^2}\int_0^{2\pi}\int_0^{2\pi}\frac{\xi - \eta}{2}\, e^{-i(\tau_1 w_1 + \tau_2 w_2)}\, dw_1 dw_2$$

In this integration we shall change variables from w_1, w_2 to ψ, χ. We have:

$$z = \frac{\xi - \eta}{2} = \frac{M_1 - M_2}{2} + \frac{L_1\cos\psi - L_2\cos\chi}{2}$$
$$= \sigma I(I_1 - I_2) + \sigma I^2(\sigma_1\cos\psi - \sigma_2\cos\chi)$$

The constant term in z we can ignore.

The functional determinant of the transformation is:

$$\begin{vmatrix} \dfrac{\partial W_1}{\partial\psi} & \dfrac{\partial W_2}{\partial\psi} \\ \dfrac{\partial W_1}{\partial\chi} & \dfrac{\partial W_2}{\partial\chi} \end{vmatrix} = 1 + \sigma_1\cos\psi + \sigma_2\cos\chi$$

We therefore have:

$$A_{\tau_1\tau_2} = \frac{\sigma I^2(-1)^\tau}{4\pi^2}\int_0^{2\pi}\int_0^{2\pi}\begin{matrix}(\sigma_1^2\cos^2\psi + \sigma_1\cos\psi - \sigma_2^2\cos^2\chi - \sigma_2\cos\chi)\times \\ e^{-i\tau_1\psi - i\tau\sigma_1\sin\psi - i\tau_2\chi - i\tau\sigma_2\sin\chi}\, d\psi d\chi\end{matrix} \tag{22}$$

where:

$$\tau = \tau_1 + \tau_2$$

If $\cos \psi$ and $\cos \chi$ are expressed in the form of exponentials:

$$\cos \theta = \frac{1}{2} (e^{i\theta} + e^{-i\theta})$$

we will have a number of integrals of the type:

$$\int_0^{2\pi} e^{-in\theta + ix \sin \theta} d\theta$$

where n is a positive or negative integer and x may be positive or negative.

The definite integral expressing Bessel's function of order n:

$$J_n(x) = \frac{1}{2\pi} \int_{-\pi}^{+\pi} e^{-in\theta + ix \sin \theta} d\theta$$

is valid for all positive and negative integral values of n, and for all positive or negative values of x. By writing this:

$$J_n(x) = \frac{1}{2\pi} \int_{-\pi}^{0} e^{-in\theta + ix \sin \theta} d\theta + \frac{1}{2\pi} \int_{0}^{\pi} e^{-in\theta + ix \sin \theta} d\theta$$

and changing the variable in the first integral to

$$\theta' = \theta + 2\pi$$

we get:

$$J_n(x) = \frac{1}{2\pi} \int_0^{2\pi} e^{-in\theta + ix \sin \theta} d\theta \qquad (23)$$

which is valid for all positive and negative integral values of n and for all positive and negative values of x. The integrals in (22) will, therefore, all be Bessel's functions of different integral orders and arguments $(-\tau\sigma_1)$ $(-\tau\sigma_2)$. By using the recurrence formulae:

$$J_{n-1}(x) - J_{n+1}(x) = 2J'_n(x)$$

$$J_{n-1}(x) + J_{n+1}(x) = \frac{2n}{x} J_n(x)$$

and

$$J_n(-x) = (-1)^n J_n(x)$$

we find:

$$A_{n_1 n_2} = \frac{\sigma I^2}{\tau} \left\{ \sigma_2 J_{n_1}(\tau\sigma_1) J'_{n_1}(\tau\sigma_2) - \sigma_1 J'_{n_1}(\tau\sigma_1) J_{n_1}(\tau\sigma_2) \right\} \qquad (24)$$

The value of A_{00} must be treated as a special case; we get from (22)

$$A_{00} = \frac{3}{2}\sigma I(I_1 - I_2)$$

and we therefore have:

$$z = \frac{3}{2}\sigma I(I_1 - I_2)$$
$$+ \sigma I^2 \sum \frac{1}{\tau}\left\{\sigma_2 J_{\tau_1}(\sigma_1\tau) J'_{\tau_2}(\sigma_2\tau) - \sigma_1 J'_{\tau_1}(\sigma_1\tau) J_{\tau_2}(\sigma_2\tau)\right\} e^{i(\tau_1 w_1 + \tau_2 w_2)} \quad (25)$$

A combination of integers giving $\tau_1 + \tau_2 = O$ gives an indeterminate result; but by going back to (22) and putting $\tau = O$ we see that for such values $A_{\tau_1\tau_2}$ is zero.

We have now obtained the Fourier expansion for the displacement of the electron along the axis and we must next obtain it for the displacement perpendicular to the axis. The radius vector to the electron in any plane perpendicular to the axis is:

$$x + iy = \rho e^{i\phi} = \sqrt{\xi\eta}\, e^{i\phi}$$

In developing this in a Fourier series it is obvious that the periodic term must be of the form

$$e^{i(\tau_1 w_1 + \tau_2 w_2 + w_3)}$$

for otherwise the angle φ would appear in the expression for the coefficients; and owing to the symmetry of the system about the axis, φ being a cyclic coördinate, it cannot appear in the result.

The expression for the coefficients in the expansion is most easily obtained by expanding:

$$(x + iy)e^{i(w_2 - w_3)} = \sum B_{\tau_1\tau_2} e^{i(\tau_1 w_1 + \overline{\tau_2 + 1} w_2)}$$

We have, from (17), (20), (21),

$$(x + iy)e^{i(w_2 - w_3)} = \sqrt{\xi\eta}\, e^{i(\varphi + w_2 - w_3)}$$
$$= \frac{e^{-i\frac{\psi}{2} - i\frac{\chi}{2}}}{\sqrt{M_1 + L_1}\ \sqrt{M_2 + L_1}}\left\{(M_1 + L_1)\cos\frac{\psi}{2} + i\sigma II_3 \sin\frac{\psi}{2}\right\}$$
$$\left\{(M_2 + L_2)\cos\frac{\chi}{2} + i\sigma II_3 \sin\frac{\chi}{2}\right\}$$

so that we have:

$$B_{\tau_1\tau_2} = \frac{1}{4\pi^2\sqrt{(M_1 + L_1)(M_2 + L_2)}}\int_0^{2\pi}\int_0^{2\pi}\left\{(M_1 + L_1)\cos\frac{\psi}{2} + i\sigma II_3 \sin\frac{\psi}{2}\right\}$$
$$\times \left\{(M_2 + L_2)\cos\frac{\chi}{2} + i\sigma II_3 \sin\frac{\chi}{2}\right\} \times e^{-i\frac{\psi}{2} - i\frac{\chi}{2}}\, e^{-i(\tau_1 w_1 + \tau_2 w_2 - w_1)}\, dw_1 dw_2$$

As before, we change the variables from w_1, w_2 to ψ, χ. The integrals again all become Bessel's functions, and the result may be written:

$$B_{\tau_1\tau_2} = -\frac{\sigma I^2}{\tau}\left\{\iota_{13}\iota_{23}J_{\tau_1}(\tau\sigma_1)J_{\tau_2}(\tau\sigma_2) - \iota_1\iota_2 J_{\tau_1+1}(\tau\sigma_1)J_{\tau_2+1}(\tau\sigma_2)\right\} \quad (26)$$

where the following notation is used:

$$\left.\begin{aligned}
&\iota_1 = \sqrt{\frac{I_1}{I}} \quad \iota_2 = \sqrt{\frac{I_2}{I}} \quad \iota_{13} = \sqrt{\frac{I_1+I_3}{I}} \quad \iota_{23} = \sqrt{\frac{I_2+I_3}{I}} \\
&\sigma_1 = \iota_1\iota_{13} \quad \sigma_2 = \iota_2\iota_{23} \\
&M_1 = \sigma I^2(\iota_1^2 + \iota_{13}^2) \quad L_1 = 2\sigma I^2\iota_1\iota_{13} \\
&M_2 = \sigma I^2(\iota_2^2 + \iota_{23}^2) \quad L_2 = 2\sigma I^2\iota_2\iota_{23}) \\
&\qquad \tau = \tau_1 + \tau_2 + 1
\end{aligned}\right\} \quad (27)$$

For $\tau = 0$ the value given for $B_{\tau_1\tau_2}$ becomes indeterminate. As special cases, we find:

$$B_{-1,0} = \frac{3}{2}\sigma I^2\iota_1\iota_{23} \quad B_{0,-1} = \frac{3}{2}\sigma I^2\iota_1\iota_{13}$$

while the coefficients for all other combinations that make $\tau = O$ vanish. The displacement of the electron in a plane perpendicular to the axis is therefore given by:

$$x + iy = \frac{3}{2}\sigma I^2\left\{\iota_1\iota_{23}e^{i(w_1+w_3)} + \iota_2\iota_{13}e^{i(w_2+w_3)}\right\} \quad (28)$$
$$-\sigma I^2\sum\frac{1}{\iota}\left\{\iota_{13}\iota_{23}J_{\tau_1}(\tau\sigma_1)J_{\tau_2}(\tau\sigma_2) - \iota_1\iota_2 J_{\tau_1+1}(\tau\sigma_1)J_{\tau_2+1}(\tau\sigma_2)\right\} \times e^{i(\tau_1 w_1 + \tau_2 w_2 + w_3)}$$

In order to express the displacements as functions of the time explicitly we must replace the angle variables by their values in terms of the mean motions by III (27). For H we must take the value of the energy in the electric field, and as far as terms of the first degree in F, the intensity of the electric field; this is, by VII (24):

$$H = -\alpha_1 = -\frac{2ms^2e^4\pi^2}{I_2} - \frac{3}{8}\frac{EI(I_1 - I_2)}{\pi^2 mse} \quad (29)$$

By (5) we find:

$$\left.\begin{aligned}\frac{w_1}{2\pi} &= \frac{w_3}{2\pi} - \frac{3}{8}\frac{EI}{\pi^2 mse} \\ \frac{w_2}{2\pi} &= \frac{w_3}{2\pi} + \frac{3}{8}\frac{EI}{\pi^2 mse} \\ \frac{w_3}{2\pi} &= \frac{4ms^2e^4\pi^2}{I^3} - \frac{3}{8}\frac{E(I_1 - I_2)}{\pi^2 mse}\end{aligned}\right\} \quad (30)$$

From (30) it follows that

$$\omega_1 + \omega_2 - 2\omega_3 = O$$

There is thus a linear relation between the mean motions and the system is therefore degenerate as there are only two fundamental frequencies. For these two frequencies we may take:

$$\omega_3 = \frac{4\pi s^2e^4m}{I^3} + \frac{3E(I_2 - I_1)}{8\pi^2 sem} \quad (31)$$

and

$$\omega' = \frac{3EI}{8\pi^2 sem} \quad (32)$$

and then we will have:

$$\omega_1 = \omega_3 - \omega' \qquad \omega_2 = \omega_3 + \omega' \quad (33)$$

The effect of the external field is therefore to produce perturbations upon the only fundamental frequency there is in the absence of the field. If higher powers of the external electric force had been kept the system would no longer appear degenerate.

If now we make use of the relations:

$$w_k = \omega_k t + \delta_k$$

the exponental terms in the displacements parallel and perpendicular to the axis will be:

$$\epsilon^{i(\tau_1 w_1 + \tau_2 w_2)t}$$

and

$$\epsilon^{i(\tau_1 w_1 + \tau_2 w_2 + w_3)t}$$

The constants, δ_k, we may take to be zero. According to ordinary dynamics we should therefore expect to find radiation of frequencies:

$$\nu = \frac{1}{2\pi}(\tau_1 w_1 + \tau_2 w_2)$$

polarized along the axis, and frequencies:

$$\nu = \frac{1}{2\pi}(1\tau\omega_1 + \tau_2\omega_2 + \omega_3)$$

circularly polarized in planes perpendicular to the axis. According to the quantum theory the frequencies are given by

$$\nu = \frac{1}{h}\left(\epsilon_{n_1' n_2' n_3'} - \epsilon_{n_1'' n_2'' n_3''}\right)$$

and in the region of long wave-lengths we have seen that this becomes

$$\nu = \frac{1}{2\pi}\left(\omega_1\tau_1 + \omega_2\tau_2 + \omega_3\tau_3\right)$$

where

$$\tau_1 = n_1' - n_1'' \qquad \tau_2 = n_2' - n_2'' \qquad \tau_3 = n_3' - n_3''$$

We should therefore expect in the case we are dealing with where there is symmetry about the axis to find two different kinds of transition from one to another stationary state: (1) those for which n_3 does not change, and accordingly the radiation will be polarized along the axis, and (2) those in which n_3 changes by one unit, corresponding to circularly polarized radiation in planes perpendicular to the axis. This gives an interpretation of Epstein's empirical rule, according to which transitions for which $n_3' - n''$ is even give rise to axially polarized light, and transitions for which it is odd give rise to light polarized perpendicularly to the axis.

In the following tables, taken from Kramers' memoir, the results of estimating the relative intensities of the components in the Stark effect in the four lines of the hydrogen spectrum are given. The theory in its present form cannot compare the intensities of different spectral lines, but only the intensities of the components of a single line.

The first column gives the transition, $n_1'n_2'n_3' - n_1''n_2''n_3''$. The second column gives the values of Z from VII (29), which in our present notation is:

$$Z = (n_1' - n_2')(n_1' + n_2' + n_3') - (n_1'' - n_2'')(n_1'' + n_2'' + n_3'') \quad (34)$$

The next three columns give the values of

$$\tau_1 = n_1' - n_1'' \qquad \tau_2 = n_2' - n_2'' \qquad \tau_3 = n_3' - n_3'' \qquad (35)$$

In the sixth column is given the value of the amplitude of the vibration in the first state and its value in the second state is given in the seventh column. In the first section of each table this value is determined by (25), corresponding to light polarized in the axis,

for which $\tau_3 = 0$, and in the second section it is determined by (26) for the circularly polarized light, for which $\tau_3 = \pm 1$. These expressions are:

$$R(\tau_1\omega_2 + \tau_2\omega_2) = \frac{2}{\tau}\left\{\sigma_2 J_{\tau_1}(\tau\sigma_1) J'_{\tau_2}(\tau\sigma_2) - \sigma_1 J'_{\tau_1}(\tau\sigma_1) J_{\tau_2}(\tau\sigma_2)\right\} \quad (36)$$

and

$$R(\tau_1\omega_1 + \tau_2\omega_2 + \omega_3) =$$

$$\frac{1}{\tau}\left\{\iota_{13}\iota_{23} J_{\tau_1}(\sigma_1\tau) J_{\tau_2+1}(\sigma_2\tau) - \iota_1\iota_2 J_{\tau_1+1}(\tau\sigma_1) J_{\tau_2+1}(\tau\sigma_2)\right\} \quad (37)$$

in which, since we are dealing with relative values, σI^2 has been taken equal to unity. The factor 2 in the first of these arises from the fact that equal and opposite rotations about the axis produce equivalent effects. The constants in (36) and (37) are determined by (27):

$$\sigma_1 = \frac{1}{n}\sqrt{n_1(n_1 + n_3)} \qquad L_1 = \sqrt{\frac{n_1}{n}}$$

$$\sigma_2 = \frac{1}{n}\sqrt{n_2(n_2 + n_3)} \qquad L_2 = \sqrt{\frac{n_2}{n}}$$

$$n = n_1 + n_2 + n_3 \qquad \iota_{13} = \sqrt{\frac{n_1 + n_3}{n}}$$

$$\tau = \tau_1 + \tau_2 + \tau_3 \qquad \iota_{23} = \sqrt{\frac{n_2 + n_3}{n}}$$

For the sixth column, the values n'_1, n'_2, n'_3 are used, and for the seventh column the values n''_1, n''_2, n''_3. The eighth and ninth columns contain the squares of the sixth and seventh, respectively. In the tenth column the estimated values of the relative intensities of the different components as given by Stark are added.

Hα 6562.8 Å. $3 \longrightarrow 2$

	Transition	Z	τ_1	τ_2	τ_3	R′	R″	R′²	R″²	Obs.
Parallel	111 ⟶ 011	2	1	0	0	0.46	0	0.21	0	1.0
	102 ⟶ 002	3	1	0	0	0.51	0	0.26	0	1.1
	201 ⟶ 101	4	1	0	0	0.62	0.57	0.38	0.33	1.2
Perpendicular	003 ⟶ 002	0	0	0	1	1.0	1.0	1.0	1.0	2.6
	111 ⟶ 002	0	1	1	—1	0.26	0	0.07	0	
	102 ⟶ 101	1	0	0	1	0.75	0.62	0.56	0.39	1.0
	102 ⟶ 011	5	1	—1	1	0	0	0	0	...
	201 ⟶ 002	6	2	2	—1	0.05	0	0.003	0	...

H_β 4861.3 Å. $4 \longrightarrow 2$

	Transition	Z	r_1	r_2	r_3	R′	R″	R'^2	R''^2	Obs.
Parallel	112 ⟶ 002	0	1	1	0	0	0	0	0	1.4
	211 ⟶ 101	2	1	1	0	0.02	0	0.0004	0	1.2
		(4)								1.0
	211 ⟶ 011	6	2	0	0	0.15	0	0.021	0	4.8
	202 ⟶ 002	8	2	0	0	0.17	0	0.030	0	9.1
	301 ⟶ 101	10	2	0	0	0.21	0.17	0.045	0.030	11.5
		(12)								1.0
	301 —— 011	14	3	—1	0	0	0	0	0	...
Perpendicular		(0)								1.4
	112 ⟶ 011	2	1	1	1	0.12	0	0.014	0	3.3
	103 ⟶ 002	4	1	0	1	0.19	0	0.036	0	12.6
	211 ⟶ 002	4	2	1	—1	0.06	0	0.004	0	
	202 ⟶ 101	6	1	0	1	0.19	0.19	0.037	0.037	9.7
		(8)								1.3
	202 ⟶ 011	10	2	—1	1	0	0	0	0	1.1
	301 ⟶ 002	12	3	0	—1	0.02	0	0.0004	0	1.0

H_γ 4340.5 Å. $5 \longrightarrow 2$

	Transition	Z	r_1	r_2	r_3	R′	R″	R'^2	R''^2	Obs.
Parallel	221 ⟶ 011	2	2	1	0	0.033	0	0.0011	0	1.6
	212 ⟶ 002	5	2	1	0	0.022	0	0.0005	0	1.5
	311 ⟶ 101	8	2	1	0	0.013	0	0.0016	0	1.0
	311 ⟶ 011	12	3	0	0	0.074	0	0.0055	0	2.0
	302 ⟶ 002	15	3	0	0	0.093	0	0.0086	0	7.2
	401 ⟶ 101	18	3	0	0	0.112	0.080	0.0125	0.0063	10.8
	401 ⟶ 011	22	4	—1	0	0	0	0	0	1(?)
Perpendicular	113 ⟶ 002	0	1	1	1	0.065	0	0.0041	0	7.2
	221 ⟶ 002	0	2	—2	—1	0.031	0	0.0009	0	
	212 ⟶ 101	3	1	1	1	0.057	0	0.0032	0	3.2
	212 ⟶ 011	7	2	0	1	0.045	0	0.0020	0	1.2
	203 ⟶ 002	10	2	0	1	0.085	0	0.0072	0	4.3
	311 ⟶ 002	10	3	1	—1	0.025	0	0.0006	0	
	302 ⟶ 101	13	2	0	1	0.088	0.089	0.0077	0.080	6.1
	302 ⟶ 011	17	3	—1	1	0	0	0	0	1.1
	401 ⟶ 002	10	4	0	—1	0.014	0	0.0002	0	1.0

H_δ 4101.7 Å. $6 \longrightarrow 2$

	Transition	Z	r_1	r_2	r_3	R′	R″	R'^2	R''^2	Obs
Parallel	222 ⟶ 002	0	2	2	0	0	0	0	0	...
	321 ⟶ 101	4	2	2	0	0.008	0	0.0001	0	1.9
	321 ⟶ 011	8	3	1	0	0.027	0	0.0007	0	1.2
	312 ⟶ 002	12	3	1	0	0.020	0	0.0004	0	1.5
	411 ⟶ 101	16	3	1	0	0.016	0	0.0003	0	1.2
	411 ⟶ 011	20	4	0	0	0.045	0	0.0020	0	1.1
	402 ⟶ 002	24	4	0	0	0.060	0	0.0036	0	2.8
	501 ⟶ 101	28	4	0	0	0.066	0.043	0.0044	0.0019	7.2
	501 ⟶ 011	32	5	—1	0	0	0	0	0	1 (?)

	222 $\longrightarrow$ 011	2	2	1	1	0.028	0	0.0008	0	1.3
	213 $\longrightarrow$ 002	6	2	1	1	0.036	0	0.0013	0	3.2
	321 $\longrightarrow$ 002	6	3	2	—1	0.017	0	0.0003	0	
Perpendicular	312 $\longrightarrow$ 101	10	2	1	1	0.033	0	0.0011	0	2.1
	312 $\longrightarrow$ 011	14	3	0	1	0.023	0	0.0005	0	1.0
	303 $\longrightarrow$ 002	18	3	0	1	0.049	0	0.0024	0	2.0
	411 $\longrightarrow$ 002	18	4	1	—1	0.013	0	0.0002	0	
	402 $\longrightarrow$ 101	22	3	0	1	0.051	0.049	0.0026	0.0024	2.4
	402 $\longrightarrow$ 011	26	4	—1	1	0	0	0	0	1.3
	501 $\longrightarrow$ 002	30	5	0	—1	0.006	0	0.00004	0	1 (?)

It will be noticed that no state, either initially or finally, in which $n_3 = O$ is included; that means that no state is counted as a stationary state in which the angular velocity of the electron about the axis is zero. Transitions which result in the same value of Z, and therefore cause the same components, are bracketed together.

In general, the agreement between the relative values of $R'^2 + R''^2$ and the estimated intensity from the photographic plates is remarkably good. Kramers gives diagrams to illustrate the comparison between his calculated intensities and those estimated by Stark and the similarity between the appearance of the calculated spectrum and the observed spectrum is striking. This investigation by Kramers furnishes almost convincing proof of the general validity of Bohr's theory.

In addition to the Stark effect in hydrogen Kramers has made similar calculations for three lines of the helium spectrum. As the helium atom has a double nucleus the separation of the components in the Stark effect is much smaller than with hydrogen, and there are no observations as yet sufficiently good to make a detailed comparison with the theory.

35. The Theory of Perturbations.

All of the applications of the quantum theory to spectroscopy that have been made in the preceding depend upon the solution of the Hamilton-Jacobi equation by the method of separation of the variables. In one important case this method cannot be applied; that is, when an atom is in an external field and the change in the mass of the electron due to relativity is taken into account. Sommerfeld has shown that the fine structure of the hydrogen and helium lines can be explained by taking this relativity change into account.

For solving such problems Bohr has developed, in the memoir referred to above, the astronomical method of perturbations. In

brief, the method consists in getting a solution of the Hamilton-Jacobi equation in the absence of the external field, and then by successive approximation obtaining a solution which exhibits the effect of the field as perturbations in the first solution. A detailed application of Bohr's method has been made by Kramers to the fine structure of the hydrogen and helium lines, and the influence of electric and magnetic fields upon it. The question of the relative intensities in the fine structure is considered and results in excellent agreement with observation have been obtained. As Kramers has promised another memoir dealing more extensively with this subject, it may be well to wait for it before giving an account of this most interesting and important work.

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DATA RELATING TO X-RAY SPECTRA

With a Brief Statement of Their Bearing on Theories of the Structure of Atoms and the Mechanism of Radiation*

By William Duane

Professor of Bio-Physics, Harvard University

The following tables contain wave-lengths in X-ray spectra that have been measured recently by means of crystal spectrometers (Bragg spectrometers).

The equation

$$\lambda = 2d \times \sin \theta \qquad (1)$$

gives the wave-length, λ, where θ is the angle made by the incident beam of X-rays with the reflecting planes of the crystal, and d is the perpendicular distance between two successive planes.

Most of the wave-lengths have been measured by means of crystals of rock salt (NaCl), or calcite ($CaCO_3$). The usually accepted value of d for rock salt (100 planes) is:

$$d = (2.814 \pm 0.018) \times 10^{-8} \text{ cm.}$$

Some discussion has arisen as to the probable value of d (100 planes) for calcite. A. H. Compton (*Physical Review*, June, 1918, p. 430) gives the value:

$$d = 3.0281 \times 10^{-8} \text{ cm.}$$

which Uhler estimates (*Physical Review*, July, 1918, p. 39) to be correct to within about ± 0.0016. Using corrections suggested by Birge (*Physical Review*, Oct., 1919, p. 361) and by Ledeux-

* This monograph is the first of a series which, when complete, will form the report of a committee of the Division of Physical Sciences of the National Research Council. This committee on X-ray spectra consists of the following members: William Duane, Harvard University, Chairman; Bergen Davis, Columbia University; A. W. Hull, General Electric Research Laboratory; D. L. Webster, Leland Stanford Junior University.

Lebard and Dauvillier (*C. R.*, Nov. 24, 1919) the value of d for calcite:

$$d = (3.0283 \pm 0.002) \times 10^{-8} \text{ cm.}$$

has been calculated from the formula

$$d = \left[\frac{MeE}{2\rho\varphi(\beta)Sc}\right]^{\frac{1}{3}}$$

where

M = molecular weight of $CaCO_3$ = 100.075
ρ = density of calcite crystal = 2.7125 $\pm$ 0.0015
E = electro-chemical equivalent of silver per E. M. U. = 0.00111827
$\varphi(\beta)$ = volume of calcite rhombohedron = 1.0963 $\pm$ 0.0007
e = charge of an electron = $(4.774 \pm 0.005) \times 10^{-10}$
S = atomic weight of silver = 107.88
c = velocity of light = 2.9986×10^{10}

The most recent direct comparison of d for calcite with d for rock salt by means of X-rays themselves has been made by Siegbahn (*Phil. Mag.*, June, 1919, p. 601). Assuming that for rock salt:

$$d = 2.814 \times 10^{-8} \text{ cm.}$$

he finds that for calcite:

$$d = 3.02904 \times 10^{-8} \text{ cm.}$$

The weight of opinion seems to incline toward calcite as a more uniform, and therefore, a better crystal than rock salt for making accurate wave-length measurements.

Since an X-ray wave-length can be measured with much greater precision than that indicated by the probable error in the value of d for either calcite or rock salt, the writer for some years has been accustomed to calculate the wave-lengths measured in his laboratory by means of the grating space for calcite:

$$d = 3.028 \times 10^{-8} \text{ cm.}$$

If the value of d ultimately selected (by international agreement, for instance) differs from this, all these wave-lengths can be changed easily in the required ratio.

Two kinds of X-radiation have been recognized: general, or continuous spectrum X-rays and characteristic X-rays. The wave-lengths of the characteristic X-rays depend upon the atomic number of the chemical element used as a target in the X-ray

tube (Moseley, *Phil. Mag.*, Dec., 1913, p. 1024, and April, 1914, p. 703). The general X-radiation contains all wave-lengths down to a certain well-defined minimum, the value of which depends upon the difference of potential, V, applied to the X-ray tube, in accordance with the Planck-Einstein quantum equation:

$$Ve = h\nu = h\frac{c}{\lambda} \qquad (2)$$

(Duane and Hunt, *Phys. Rev.*, Aug., 1915, p. 166).

In 1913 W. H. Bragg tested the quantum law as applied to characteristic X-rays, the wave-lengths of which had actually been measured. He used Whiddington's estimates of the voltages, V, required to produce the characteristic X-rays.

In 1914 the writer made some experiments to test the law in the case of the *general* radiation. In these experiments a fairly constant measured voltage was applied to the X-ray tube, and the average (or effective) wave-length was determined by measuring the coefficient of absorption of the rays in aluminium, and by calculating the wave-length from the known relation between the two.

The experiments showed in each case that Ve had the same order of magnitude as $h\nu$.

Measurements of h by means of the limiting values of the wave-lengths in the general X-radiation have been made as follows:

(Millikan's value of $e = 4.774 \times 10^{-10}$ E. S. U. has been used in the computations.)

Duane and Hunt	(*Phys. Rev.*, Aug., 1915, p. 166)	6.51×10^{-27}
Hull	(*Phys. Rev.*, Jan., 1916, p. 156)	6.59×10^{-27}
D. L. Webster	(*Phys. Rev.*, June, 1916, p. 599)	6.53×10^{-27}
Blake and Duane	(*Phys. Rev.*, Dec., 1917, p. 624)	6.555×10^{-27}
Müller	(*Phys. Zeit.*, Nov., 1918, p. 489)	6.58×10^{-27}
Wagner	(*Ann. d. Physik*, Dec., 1918, p. 401)	6.49×10^{-27}

Four kinds of wave-lengths (and vibration frequencies) may be regarded as associated with each series of characteristic X-rays:

(*a*) Critical ionization wave-lengths.

(*b*) Critical absorption wave-lengths.

(*c*) The wave-lengths in the emission lines of the series.

(*d*) The quantum wave-lengths.

(*a*) A critical ionization wave-length characteristic of a chemical element is a wave-length such that, if the element is present in a gas through which X-rays pass, X-rays of shorter wave-length than the critical value ionize the gas more strongly than X-rays

of longer wave-length do. The increase in ionization may be ascribed to an increase in the emission of high speed electrons from the atoms of the chemical element due to the passage of X-rays across them.

(*b*) A critical absorption wave-length characteristic of a chemical element is a wave-length such that, if the element lies in the path of the X-rays, it absorbs the X-rays of shorter wave-length than the critical value to a greater extent than it does X-rays of longer wave-length.

(*c*) Each series of X-rays contains a number of emission lines of different wave-lengths.

(*d*) A quantum wave-length is a wave-length such that, if it is substituted in the quantum equation (2), it gives the energy of the electron (or voltage applied to the X-ray tube) required to produce the series of X-rays with which it is associated.

It has been known for some time that all of these four kinds of characteristic wave-lengths that belong to the same X-ray series lie together in the same region of the X-ray spectrum.

Recent improvements in the methods of measuring wave-lengths have made it possible to prove (A) that a critical ionization wave-length characteristic of a chemical element (iodine, for example) equals the critical absorption wave-length characteristic of the same element (and associated with the same series) to within less than one-tenth of one per cent (Duane and Hu, *Phys. Rev.*, Oct., 1918, p. 3721); (B) that the shortest wave-length in the K series of X-rays exceeds the critical absorption wave-length associated with the same series by a fraction of one per cent (one-fourth of one per cent for rhodium, and one-half of one per cent for tungsten) (Duane and Hu, *Loc. Cit.*, and Duane and Stenström, *Nat. Acad. Proc.*, Aug., 1920); and (C) that the quantum wave-length for the K series (of rhodium, for instance) is a fraction of one per cent shorter than the shortest emission wave-length in the K series (Webster, *Phys. Rev.*, June, 1916, p. 599). This means that, according to (B), the quantum wave-length coincides with the corresponding critical absorption wave-length to within the limits of error of the measurements. Webster has also determined two of the quantum wave-lengths in the L series (of platinum) (*Phys. Rev.*, June, 1917, p. 571), and these lie close to two of the three critical absorption wave-lengths in the same series.

It has been found by experiment that within the limits of experimental error the differences between the K critical absorption

frequency and the L critical absorption frequencies equal, respectively, the frequencies of the α lines in the K series, and that the difference between the K critical absorption frequency and one of the M critical absorption frequencies equals the frequency of the β line in the K series (Duane and Shimizu, *Phys. Rev.*, July, 1919, p. 67; Duane and Stenström, *Nat. Acad. Proc.*, Aug., 1920).

The following values of the emission and absorption wave-numbers illustrate these laws. The K and L critical absorption wave-numbers, Ka, La_1, La_2 and La_3, have been computed from the wave-lengths for tungsten contained in Tables 2 and 3. The K emission wave-numbers $K\alpha_1$, $K\alpha_2$, $K\alpha_3$ and $K\beta$ have been computed from the wave-lengths for tungsten contained in Table 8. The M critical absorption wave-number, Ma_3, has been estimated from the data in Tables 4 and 13.

TABLE A

$Ka - La_1 = 4.792 \pm 0.003$	$\alpha_1 = 4.7938 \pm 0.001$
$Ka - La_2 = 4.685 \pm 0.003$	$\alpha_2 = 4.6858 \pm 0.0007$
$Ka - La_3 = 4.639 \pm 0.006$	$\alpha_3 = 4.65 \pm 0.02$
$Ka - Ma_3 = 5.433$	$\beta = 5.429$

It has been found by experiment, also, that several (not all) of the lines in the L series have emission frequencies equal to the differences between the critical absorption frequencies in the L series and those in the M series (Duane and Patterson, *Nat. Acad. Proc.*, Sept., 1920).

The following wave-numbers illustrating this have been computed from the data for uranium and thorium, contained in Tables 3, 4 and 11:

TABLE B

U	Th	U	Th	U	Th
$La_1 - Ma_1 = 1.099$	1.047	$La_1 - Ma_2 = 1.085$	1.034	$La_1 - Ma_3 = 1.038$	0.988
$L\alpha_1 = 1.098$	1 045	$L\alpha_2 = 1.085$	1.032	....	...
$La_2 - Ma_1 = 1.403$	1.322	$La_2 - Ma_2 = 1\ 389$	1.309	$La_2 - Ma_3 = 1.342$	1.263
....	...	$L\beta_1 = 1\ 389$	1.305	....	...
$La_3 - Ma_1 = 1.472$	1.385	$La_3 - Ma_2 = 1.458$	1.372	$La_3 - Ma_3 = 1.411$	1.326
....	...	....	...	$L\beta_3 = 1.408$	1.319

Lines corresponding to some of the differences between critical absorption frequencies have not been observed. The vacancies are indicated by dots in the table.

Several pairs of lines in the emission spectra of a chemical element appear to have the same frequency difference (Kossel, Sommerfeld, Swinne, etc.). For instance: (*a*) the difference in frequency between the α_1 and α_2 lines in the K series equals that between the

$\bar{\beta}_1$ and α_2 lines in the L series and also equals that between the γ_1 and β_2 lines in the L series; (*b*) the difference in frequency between the α_1 and α_2 lines in the L series equals that between the β and α lines in the M series, etc. As we increase the precision of our measurements, however, the number of these frequency differences that equal each other appears to decrease. The relations become more complex.

At one time the difference between the frequencies of the β and α lines in the K series was supposed to equal that of the α line in the L series (Kossel). Recent experiments, however, have proved this relation to be inexact. A more accurate law can be formulated by taking single components of the Kβ and Kα groups of lines and by introducing the frequencies of lines in the M series.

TABLE 1

CRITICAL IONIZATION WAVE-LENGTHS, K SERIES, $\lambda \times 10^8$ cm.

Ionization Method. For Calcite $d = 3.028 \times 10^{-8}$ cm.

Chemical Element	Atomic Number	Wave-Length
Bromine	35	0.9179 ± 9
Iodine	53	0.3737 ± 3

References: Blake and Duane, *Phys. Rev.*, July, 1917, p. 98, and Dec., 1917, p. 697. Duane and Hu, *Phys. Rev.*, June, 1918, p. 448, and Dec., 1919, p. 516.

TABLE 2

CRITICAL ABSORPTION WAVE-LENGTHS, K SERIES, $\lambda \times 10^8$ cm.

Chemical Element	Atomic Number	Photographic Methods. For Rock Salt $d = 2.814 \times 10^{-8}$ cm.			Ionization Methods. For Calcite $d = 3.028 \times 10^{-8}$ cm.
		de Broglie	Wagner	Fricke	Blake, Duane, Hu
Magnesium	12			9.5112	
Aluminium	13			7.9470	
Phosphorus	15			5.7580	
Sulphur	16			5.0123	
Chlorine	17			4.3844	
Argon	18			3.8657	
Potassium	19			3.4345	
Calcium	20			3.0633	
Scandium	21			2.7517	
Titanium	22			2.4937	
Vanadium	23			2.2653	
Chromium	24			2.0675	
Manganese	25				1.8892
Iron	26		1.740		1.7396
Cobalt	27				1.6018
Nickel	28		1.485		1.4890
Copper	29	1.388	1.375		1.3785

TABLE 2 (*Continued*)

Chemical Element	Atomic Number	de Broglie	Wagner	Siegbahn-Jönsson	Blake, Duane, Hu	
Zinc	30				1.2963	
Gallium	31				1.1902	
Germanium	32				1.1146	
Arsenic	33				1.0435	
Selenium	34	1.003			0.9790	
Bromine	35	0.916	0.917		0.9179	
Rubidium	37	0.812			0.8143	
Strontium	38	0.767			0.7696	
Yttrium	39				0.7255	
Zirconium	40	0.684			0.6872	
Niobium	41	0.648			0.6503	
Molybdenum	42	0.614			0.6184	
Ruthenium	44				0.5584	
Rhodium	45				0.5330	
Palladium	46	0.505	0.513		0.5075	
Silver	47	0.482	0.484		0.4850	
Cadmium	48	0.460	0.462	0.4629	0.4632	
Indium	49				0.4434	
Tin	50	0.421	0.422	0.4231	0.4242	
Antimony	51	0.401	0.405		0.4065	
Tellurium	52	0.385	0.383	0.3877	0.3896	
Iodine	53	0.369	0.369	0.3715	0.3737	
Caesium	55	0.340		0.3436	0.3444	
Barium	56	0.327	0.331	0.3306	0.3307	
Lanthanum	57	0.313		0.3186	0.3188	
Cerium	58	0.300	0.298	0.3064	0.3068	
					Duane, Fricke, Shimizu, Stenström	
					First Order	Higher Orders
Praseodymium	59			0.2946		
Neodymium	60		0.282	0 2835	0.2861	
Samarium	62			0.2636		
Europium	63			0.2543		
Gadolinium	64			0.2456		
Terbium	65				0.2398	
Dysprosium	66			0.2294	0.2308	
Holmium	67			0.2214		
Thulium	69	0.208				
Neo-Ytterbium	70	0.2015				
Lutecium	71	0.195				
Tungsten	74				0.1783	0.17806
Osmium	76				0.1683	
Platinum	78	0.152		0.1578	0.1582	0.1581
Gold	79	0.149		0.1524	0.1537	0.1532
Mercury	80	0.146		0 1479	0.1493	0.1488
Thallium	81	0.142		0.1427	0.1448	0.1449
Lead	82	0.138		0.1385	0.1412	0.1409
Bismuth	83	0.133		0.1346	0.1375	0.1369
Thorium	90			0.1127	0.1139	0.1124
Uranium	92			0.1048	0.1075	

Reference to Table 2: de Broglie, *Journ. de Physique*, May-June, 1916, p. 161, and *C. R.*, March 22, 1920, p. 725. Wagner, *Ann. d. Phys.*, March, 1915. Blake and Duane, *Phys. Rev.*, July, 1917, p. 98, and Dec., 1917, p. 698. Duane and Hu, *Phys. Rev.*, June, 1918, p. 488, and Dec., 1919, p. 516. Duane and Shimizu, *Phys. Rev.*, Feb., 1919, p. 159 and Dec., 1919, p. 523. Siegbahn and Jönsson, *Physik. Zeit.*, 1919, p. 251. Fricke, *Phys. Rev.*, Sept., 1920, p. 202. Duane, Fricke and Stenström, *Nat. Acad. Proc.*, Oct., 1920, p. 607.

TABLE 3

CRITICAL ABSORPTION WAVE-LENGTHS IN THE L SERIES, $\lambda \times 10^8$ cm.

		Photographic Methods. For Rock Salt $d = 2.714 \times 10^{-8}$ cm.						Ionization Method. For Calcite $d = 3.028 \times 10^{-8}$ cm.		
Chemical Element	At. No.	de Broglie a_1	a_2	a_3	Wagner a_1	a_2	a_3	Duane and Patterson a_1	a_2	a_3
Tungsten	74	1.215	1.083	.....	.....	.....	..	1.2136 ± 1	1.0726 ± 5	1.024 ± 3
Platinum	78	1.069	0.930	.....	1.072	0.934	..	1.0704 ± 3	0.9321 ± 3	0.8885 ± 9
Gold	79	1.038	0.898	0.858	1.036	0.914	..	1.0383 ± 3	0.8993 ± 3	0.8606 ± 8
Mercury	80	1.006	.....	.....	.....	.....	..	1.0067 ± 5	0.8700 ± 3	0.8335 ± 9
Thallium	81	0.974	0.840	.....	.....	.....	..	0.9776 ± 3	0.8415 ± 3	0.8055 ± 14
Lead	82	0.945	0.811	.....	.....	.....	..	0.9497 ± 9	0.8133 ± 3	0.7803 ± 9
Bismuth	83	0.921	0.786	0.753	.....	.....	..	0.9216 ± 3	0.7872 ± 3	0.7532 ± 9
Radium	88	0.802	0.668	.....	.....	.....	..			
Thorium	90	0.757	0.624	0.604	.....	.....	..	0.7596 ± 3	0.6286 ± 3	0.6044 ± 7
Uranium	92	0.718	0.588	0.564	.....	.....	..	0.7214 ± 3	0.5918 ± 3	0.5685 ± 7

References: de Broglie, *Journ. de Phys.*, May-June, 1916, p. 161, and Jan., 1919, p. 31. Wagner, *Ann. d. Phys.*, March, 1915. Duane and Patterson, *Nat. Acad. Proc.*, Sept., 1920.

TABLE 4

CRITICAL ABSORPTION WAVE-LENGTHS IN THE M SERIES, $\lambda \times 10^8$ cm.

Chemical Element	At. No.	Photographic Method. For Rock Salt $d = 2.814 \times 10^{-8}$ cm. a_1	a_1'	a_2	a_3
Thorium	90	3.721		3.552	3.058
Uranium	92	3.491	3.459	3.326	2.873

Reference: Wilhelm Stenström, Doctor's Dissertation, Lund, 1919.

TABLE 5

EMISSION WAVE-LENGTHS IN THE K SERIES, $\lambda \times 10^8$ cm.

For Rock Salt $d = 2.814 \times 10^{-8}$ cm. For Calcite $d = 3.0290 \times 10^{-8}$ cm.

Chemical Element	α_1	$(\alpha_1\alpha_2)$	α_1'	α_3	α_4	α_5	α_6	β_3	β'	β_1	β''	β_2
11 Na		11.8836	11.835	11.8024	11.7814					11.591		
12 Mg		9.86775	9.8265	9.79940	9.78620	9.7302	9.7118	9.647		9.53450		
13 Al		8.31940	8.28560	8.26460	8.25300	8.20580	8.18920	8.025		7.94050		
14 Si		7.10917	7.083	7.06382	7.05372	7.014	7.003	6.7933	6.7442	6.73933		
15 P		6.14171		6.10219	6.09500			5.8204		5.78513		
16 S		5.36066		5.32833	5.32175	5.277		5.047		5.01913		
17 Cl	4.71870									4.39450	4.391	
19 K	3.73386									3.44638	3.44270	
20 Ca	3.35186									3.08297	3.07957	3.06740
21 Sc	3.02526									2.77366		2.755(5)
22 Ti									2.51506	2.50874		2.49367
23 Va									2.28526	2.27968		2.26537
24 Cr	2.28517								2.083	2.079		
25 Mn									1.907	1.902		
26 Fe	1.93239								1.75884	1.75397		
27 Co	1.78524									1.61715		1.606
28 Ni	1.65467								1.49811	1.49669		1.48403
29 Cu	1.53736									1.38887		1.382

References: Manne Siegbahn, *Phil. Mag.*, June, 1919, p. 601. Manne Siegbahn and A. B. Leide, *Phil. Mag.*, Nov., 1919, p. 647. E. Hjalmar, *Zeit. f. Physik*, I Bd. 5 Ht. 1920, p. 439. Many of the wave-lengths in this table were kindly sent me by Professor Siegbahn, in whose laboratory the experiments were performed by Mr. Hjalmar.

TABLE 6

EMISSION WAVE-LENGTHS IN THE K SERIES, $\lambda \times 10^8$ cm.

Chemical Element	Atomic Number	α_2	α_1	β
Gallium	31	1.34161 ± 4	1.33785 ± 4	1.20591 ± 6

For Rock Salt d = 2.814 × 10^{-8} cm. For Calcite d = 3.0307 × 10^{-8} cm.

References: H. S. Uhler and E. D. Cooksey, *Phys. Rev.*, Dec., 1917, p. 645. Method; Photographic. Specially designed spectrometer.

TABLE 7

EMISSION WAVE-LENGTHS IN THE K SERIES, $\lambda \times 10^8$ cm.

Ionization Method.

Chemical Element	Atomic Number	α_2	α_1	β	γ
Rhodium	45	0.619	0.614	0.545	0.534
Palladium	46	0.589	0.583	0.516	0.503
Silver	47	0.562	0.557	0.495	0.488

Reference: X-Rays and Crystal Structure, W. H. and W. L. Bragg, 1915.

TABLE 8

EMISSION AND ABSORPTION WAVE-LENGTHS IN THE K SERIES, $\lambda \times 10^8$ cm.

Ionization Method. For Calcite d = 3.028 × 10^{-8} cm.

Chemical Element	At. No.	α_2	α_1	β	γ	Absorption
Molybdenum	42	0.71212±8	0.70783±7	0.63110±7	0.6197±2	0.61842±14
Rhodium	45	0.61636±15	0.61210±15	0.54527±20	0.5342±2	0.5330 ±5
Tungsten	74	0.21341±3	0.20860±4	0.18420±3	0.17901±6	0.17806±7

Method; ionization. The wave-lengths in this table are the weighted mean values obtained from measurements in several different orders. For molybdenum and rhodium these orders are the first and second, and for tungsten they are the first, second, third, fourth and in one case the fifth. A second β line in the spectrum of molybdenum has been observed with a wave-length

of about Kβ = 0.632 angström, and also a third α line in the spectrum of tungsten with a wave-length of about Kα_3 = 0.215 angström.

References: Duane and Hu, *Phys. Rev.*, June, 1918, p. 489, and Oct., 1919, p. 369. Duane and Patterson, Duane and Stenström, *Phys. Rev.*, April, 1920, p. 329, and *Nat. Acad. Proc.*, Aug., 1920.

TABLE 9

EMISSION AND ABSORPTION WAVE-LENGTHS IN THE K SERIES OF TUNGSTEN, $\lambda \times 10^8$ cm.

Line	Photographic Methods. For Rock Salt $d = 2.814 \times 10^{-8}$ cm. For Calcite $d = 3.02904 \times 10^{-8}$ cm.			Ionization Method. For Calcite $d = 3.028 \times 10^{-8}$ cm.	
	Ledoux-Lebard, Dauvillier	Dershem	Siegbahn	Duane, Shimizu	Duane, Stenström
α_2	0.2128	0.2124	0.21352	0.2134	0.21341
α_1	0.2053	0.2076	0.20885	0.2087	0.20860
β	0.1826	0.1834	0.18436	0.1842	0.18420
γ	0.1768	0.1784	0.17940	..	0.17901
Absorption	..	..	...	0.1785	0.17806

References to Table 9: Ledoux-Lebard and Dauvillier, *Comptes Rendus*, Dec., 1916. Dershem, *Phys. Rev.*, June, 1918, p. 461. Duane and Shimizu, *Phys. Rev.*, April, 1919, p. 306; July, 1919, p. 68. Siegbahn, *Phil. Mag.*, Nov., 1919, p. 639. Duane and Stenström, *Phys. Rev.*, April, 1920, p. 329; and *Nat. Acad. Proc.*, Aug., 1920.

Note to Table 10: The values of the wave-lengths in this table for molybdenum, rhodium and tungsten have been taken from Table 8. These have been calculated from $d = 3.028 \times 10^{-8}$ cm. for calcite.

The values for gallium have been taken from Table 6.

All the other wave-lengths have been measured by Siegbahn and his co-workers at Lund.

TABLE 10

EMISSION WAVE-LENGTHS IN THE K SERIES, $\lambda \times 10^8$ cm.

Photographic Methods. For Rock Salt $d = 2.814 \times 10^{-8}$ cm.
For Calcite $d = 3.028 \times 10^{-8}$ cm.

Chemical Element	Atomic Number	α_2	α_1	α_3	α_4	β_1	γ
Sodium	11	...	11.8836	11.8024	11.7814	11.591	....
Magnesium	12	...	9.8675	9.79940	9.78620	9.53450	....
Aluminium	13	...	8.31940	8.26460	8.25300	7.94050	....
Silicon	14	...	7.10917	7.06382	7.05372	6.73933	....
Phosphorus	15	...	6.14171	6.10219	6.09500	5.78513	....
Sulphur	16	...	5.36066	5.32833	5.32175	5.01913	....
Chlorine	17	...	4.71870	4.692		4.39450	....
Potassium	19	3.738	3.73386	3.724		3.44638	....
Calcium	20	3.359	3.35186	3.328		3.08297	3.06740
Scandium	21	3.032	3.02526	3.011		2.77366	2.755(5)
Titanium	22	2.746	2.742	2.729		2.50874	2.49367
Vanadium	23	2.502	2.498	....	....	2.27968	2.26537
Chromium	24	2.288	2.28517	....	....	2.08144	2.069
Manganese	25	2.097	2.093	....	....	1.902	1.892
Iron	26	1.932	1.93239	....	....	1.75397	1.736
Cobalt	27	1.785	1.78524	....	....	1.61715	1.606
Nickel	28	1.657	1.65467	....	....	1.49669	1.48403
Copper	29	1.543	1.53736	....	....	1.38887	1.382
Zinc	30	1.437	1.433	....	....	1.294	1.281
Gallium	31	1.34161	1.33785	....	....	1.20591	....
Germanium	32	1.261	1.257	....	....	1.131	1.121
Arsenic	33	1.174	1.170	....	....	1.052	1.038
Selenium	34	1.109	1.104	....	....	0.993	....
Bromine	35	1.040	1.035	....	....	0.929	0.914
Rubidium	37	0.926	0.922	....	....	0.825	0.813
Strontium	38	0.876	0.871	....	....	0.779	0.767
Yttrium	39	0.840	0.835	....	....	0.746	0.733
Zirconium	40	0.793	0.788	....	....	0.705	....
Niobium	41	0.754	0.749	....	....	0.669	0.657
Molybdenum	42	0.71212	0.70783	....	....	0.63110	0.6197
Ruthenium	44	...	0.645	....	....	0.574	....
Rhodium	45	0.6164	0.6121	....	....	0.5453	0.5342
Palladium	46	0.590	0.586	....	....	0.521	....
Silver	47	0.567	0.562	....	....	0.501	0.491
Cadmium	48	0.543	0.538	....	....	0.479	....
Indium	49	0.515	0.510	....	....	0.453	0.440
Tin	50	0.490	0.487	....	....	0.432	....
Antimony	51	0.472	0.468	....	....	0.416	0.408
Tellurium	52	...	0.456	....	....	0.404	....
Iodine	53	...	0.437	....	....	0.388	....
Caesium	55	0.402	0.398	....	....	0.352	....
Barium	56	0.393	0.388	....	....	0.343	....
Lanthanum	57	0.376	0.372	....	....	0.329	....
Cerium	58	0.360	0.355	....	....	0.314	....
Praseodymium	59	0.347	0.342	....	....	0.301	....
Neodymium	60	0.335	0.330	....	....	0.292	....
Tungsten	74	0.21341	0.20860	....	....	0.18420	0.17901

TABLE 11

EMISSION WAVE-LENGTHS IN THE L SERIES, $\lambda \times 10^8$ cm.

Photographic Methods. For Rock Salt $d = 2.814 \times 10^{-8}$ cm.
For Calcite $d = 3.028 \times 10^{-8}$ cm.

Chemical Element	At. No.	l	α_2	α_1	α_3	η	β_4	β_1	β_3	β_2	β_5	γ_1	γ_2	γ_3	γ_4
Zinc	30	...	...	12.346	...	..	...	...	...	...	..	...	...	...	...
Arsenic	33	...	...	9.701	...	..	...	9.449	...	...	..	...	...	...	...
Bromine	35	...	...	8.391	8.360	..	...	8.141	...	...	..	...	...	...	...
Rubidium	37	...	...	7.335	7.305	..	...	7.091	...	...	..	...	...	...	...
Strontium	38	...	...	6.879	...	..	...	6.639	...	...	..	...	...	...	...
Yttrium	39	...	...	6.464	6.440	..	...	6.227	...	...	..	...	...	...	...
Zirconium	40	...	...	6.083	6.057	..	...	5.851	...	...	..	5.386	...	...	...
Niobium	41	...	5.731	5.724	5.709	..	...	5.493	5.317	...	..	...	...	...	...
Molybdenum	42	...	5.410	5.403	5.381	..	...	5.175	...	...	..	...	...	...	...
Ruthenium	44	...	4.853	4.83567	4.823	..	...	4.61100	...	...	..	4.17282	...	...	...
Rhodium	45	...	...	4.587$_{78}$	4.577	..	...	4.364$_{90}$	...	...	..	3.935$_{70}$	...	...	...
Palladium	46	...	4.374	4.358$_{50}$	4.352	..	4.071	4.137$_{30}$	3.904	4.030	..	3.716$_{36}$	3.597		...
Silver	47	...	4.155	4.145$_{64}$	4.133	..	3.861	3.926$_{64}$	3.698	3.823	..	3.514$_{85}$	...	...	...
Cadmium	48	...	3.959	3.947$_{82}$	...	..	3.676	3.730$_{08}$	3.514	3.639	..	3.328$_{00}$	...	...	...
Indium	49	...	3.774	3.763$_{67}$	...	..	...	3.547$_{83}$	3.354	...	..	3.155$_{29}$	...	...	...
Tin	50	...	3.604	3.591$_{93}$	...	..	3.337	3.377$_{62}$	3.172	3.300	..	2.994$_{60}$	2.903	2.889	2.831
Antimony	51	...	3.443	3.431$_{77}$	...	..	3.184	3.218$_{36}$	3.021	3.149	..	2.845$_{07}$	2.782		...
Tellurium	52	...	3.299	3.281$_{69}$	...	..	3.044	3.069$_{64}$	2.881	3.007	..	2.706$_{13}$	...	...	...
Iodine	53	...	3.155	3.141$_{36}$	...	..	2.911	2.930$_{66}$	2.750	2.873	..	2.577$_{12}$	...	...	...
Caesium	55	...	2.899	2.885$_{87}$	...	..	2.668	2.677$_{50}$	2.514	2.629	..	2.359$_{50}$	2.234		...
Barium	56	...	2.786	2.769$_{31}$	...	..	2.558	2.562$_{24}$	2.407	2.520	..	2.236$_{25}$	...	...	...
Lanthanum	57	...	2.674	2.659$_{21}$	...	..	2.453	2.452$_{94}$	2.307	2.414	..	2.136$_{80}$	...	...	...
Cerium	58	...	2.573	2.555$_{69}$	...	..	2.357	2.350$_{61}$	2.212	2.307$_{4}$	..	2.044$_{00}$	2.003		...

TABLE 11 (*Continued*)

EMISSION WAVE-LENGTHS IN THE L SERIES, $\lambda \times 10^8$ cm.

Photographic Methods. For Rock Salt $d = 2.814 \times 10^{-8}$ cm.

For Calcite $d = 3.028 \times 10^{-8}$ cm.

Chemical Element	At. No.	l	α_2	α_1	α_3	η	β_4	β_1	β_2	β_3	β_5	γ_1	γ_2	γ_3	γ_4
Praseodymium	59	...	2.472	2.457_{35}	...	..	...	2.253_{53}	2.120	2.217	..	1.956_{41}	1.937	1.933	...
Neodymium	60	...	2.379	2.364_{94}	...	..	2.167	2.167	2.036	2.128	..	1.873_{43}	1.803	1.775	...
Samarium	62	...	2.210	2.200	...	..	...	1.993_{17}	1.884	1.965	..	1.725	1.659		...
Europium	63	...	2.131	2.121	...	..	1.923	1.918	1.810	1.888	..	1.662	1.599	1.590	...
Gadolinium	64	...	2.054	2.043	...	..	1.851	1.844	1.744	1.811	..	1.597	(1.562)	(1.558)	...
Terbium	65	...	1.983	1.973	...	1.935	1.784	1.775	1.682	1.745	1.659	1.531	1.477	1.470	1.437
Dysprosium	66	...	1.916	1.907	...	..	1.721	1.709	1.622	1.683	..	1.470	1.422	1.418	...
Holmium	67	...	1.854	1.843	...	...	1.657	1.646	1.568	1.620	..	1.415	1.369	1.365	...
Erbium	68	...	1.794	1.783	...	1.725	1.599	1.586	1.514	1.560	..	1.367	1.323	1.316	...
Aldebaranium	70	1.892	1.681	1.670	...	1.618	1.490	1.474	1.414	1.451	1.422	1.267	1.228	1.223	...
Cassiopeium	71	1.834	1.629	1.619	...	..	1.437	1.421	1.368	1.399	..	1.224	1.188	1.183	...
Tantalum	73	...	1.528	1.518	...	1.435	1.343	1.323	1.280	1.303	..	1.135	1.101	1.097	...
Tungsten	74	1.675_{06}	1.484_{52}	1.473_{43}	...	1.4177	1.298_{74}	1.279_{17}	1.24191	1.260_{00}	1.2031	1.095_{53}	1.06584	1.059_{65}	1.026_{47}
Osmium	76	...	1.398	1.388	...	..	1.214	1.194	1.167	1.176	..	1.021	...	...	...
Iridium	77	1.840	1.360	1.350	...	..	1.176	1.154	1.133	1.138	1.101	0.989	0.962	0.956	0.917
Platinum	78	1.499	1.323	1.313	...	1.242	1.142	1.120	1.101	1.098	1.072	0.958	0.933	0.929	0.900
Gold	79	1.457	1.283	1.271	...	1.197	1.102	1.080	1.065	1.059	1.035	0.922	0.898	0.894	0.869
Mercury	80	...	1.251	1.240	...	..	...	1.049	1.042	...	..	0.896	...	...	...
Thallium	81	1.385	1.215	1.205	...	1.124	1.036	1.012	1.006	0.998	0.977	0.864	0.844	0.840	0.808
Lead	82	1.348	1.186	1.175	...	1.091	1.008	0.983	0.983	0.968	..	0.842	0.820	0.816	0.792
Bismuth	83	1.317	1.153	1.144	...	1.059	0.977	0.950	0.954	0.937	0.923	0.810	0.794	0.790	0.762
Pollonium	84	...	...	1.101	...	..	...	0.920	...	...	..	...	...	...	...
Radium	88	...	...	1.010	...	..	...	...	...	...	..	...	...	...	...
Thorium	90	1.117	0.969	0.957	...	..	...	0.766	0.797	0.758	..	0.654	0.635		...
Uranium	92	1.066	0.922	0.911	...	..	...	0.720	0.756	0.710	..	0.615	0.596		...

Reference: These wave-lengths have been measured by Siegbahn and his co-workers at Lund.

TABLE 12

EMISSION WAVE-LENGTHS IN THE L SERIES OF TUNGSTEN, $\lambda \times 10^8$ cm.

Photographic Methods. For Rock Salt $d = 2.814 \times 10^{-8}$ cm.					Ionization Methods. For Calcite $d = 3.028 \times 10^{-8}$ cm.	
Line	**Gorton**	**Dershem**	**Overn**	**Siegbahn**	**A. H. Compton**	**Duane and Patterson**
l				1.67505		1.6756 ± 10
α_2	1.476	1.4828	1.4839	1.48452	1.4840	1.4839 ± 3
α_1	1.466	1.4722	1.4731	1.47348	1.4728	1.47306 ± 11
η		1.4163		1.4177		1.4176 ± 7
					1.3360	
β_4	1.292	1.2977	1.2984	1.29874	1.2982	1.2985 ± 4
	1.283	1.2868	1.2872	1.2871		
β_1	1.275	1.2784	1.2793	1.27917	1.2787	1.27892 ± 9
β_3	1.256	1.2586	1.2598	1.26000	1.2598	1.2601 ± 3
β_2	1.237	1.2416	1.2434	1.24191	1.2416	1.24193 ± 12
			1.2355	1.2395		
		1.2202	1.2212	1.2205	1.2183	
			1.2132	1.2118		
		1.2098	1.2097			
β_5		1.1773	1.2021	1.2031		1.2040 ± 7
		1.1292	1.1302	1.1284		
γ_1	1.940	1.0953	1.0967	1.09553	1.0961	1.09608 ± 7
			1.0794			
		1.0705	1.0724			
γ_2		1.0648	1.0659	1.06584	1.0650	1.0655 ± 4
γ_3	1.057	1.0587	1.0596	1.05965	1.0580	1.0596 ± 3
		1.0427	1.0446		1.0396	
γ_4	1.025	1.0253	1.0263	1.02647	1.0247	1.0261 ± 6

References: W. S. Gorton, *Phys. Rev.*, Feb., 1916, p. 203, and March, 1916, p. 334. A. H. Compton, *Phys. Rev.*, June, 1916, p. 646. E. Dershem, *Phys. Rev.*, June, 1918, p. 461. O. B. Overn, *Phys. Rev.*, Aug., 1919, p. 137. Manne Siegbahn, *Phil. Mag.*, Nov., 1919, p. 639. Duane and Patterson, *Phys. Rev.*, Dec., 1920, p. 526.

NOTE.—In order to compare the wave-lengths measured by the photographic method with those measured by the ionization method three or four units must be subtracted from the fourth decimal place of the former. This correction comes from a slight difference between the values assumed for the grating space of calcite.

For the details of the specially designed spectrometer see the articles referred to.

There is some question as to whether the very faint lines (which are not marked by a letter) belong to the emission spectrum of tungsten or not.

TABLE 13

EMISSION WAVE-LENGTHS IN THE M SERIES, $\lambda \times 10^8$ cm.

Photographic Method.

For Rock Salt $d = 2.814 \times 10^{-8}$ cm.

Chemical Element	Atomic Number	α	β	γ	δ	ϵ
Uranium	92	3.9014	3.7083	3.4714	2.943	2.813
Thorium	90	4.1292	3.9333	3.6565	3.127	3.006
Bismuth	83	5.1072	4.8993	4.5238		
Lead	82	5.2751	5.0648	4.6637		
Thallium	81	5.4499	5.2384	4.802		
Gold	79	5.819	5.601	5.115		
Platinum	78	6.035	5.818	5.295		
Iridium	77	6.245	6.029			
Osmium	76	6.477	6.250			
Tungsten	74	6.976	6.749	6.091		
Tantalum	73	7.237	7.012			
Lutecium	71	7.818	7.593			
Ytterbium	70	8.130	7.898			
Erbium	68	8.770	8.561			
Holmium	67	9.123	8.930			
Dysprosium	66	9.509	9.313			

Reference: Wilhelm Stenström, Doctor's Dissertation, Lund, 1919.

TABLE 14

EMISSION WAVE-LENGTHS IN THE M SERIES, $\lambda \times 10^8$ cm.

For Selenite log 2d = 1.18300

Chemical Element	Atomic Number	α_1	β_1	β_3	γ_1	γ_2	γ_3
Bismuth	83	5.124	4.915	4.604	4.534	3.932	3.840
Lead	82	5.290	5.078		4.675	4.073	
Thallium	81	5.468	5.254				
Mercury	80	5.649	5.439				
Gold	79	5.848	5.632	5.446	5.154	4.530	4.439
Platinum	78	6.049	5.831	5.649	5.329	4.733	4.623

Reference: J. C. Karcher, *Phys. Rev.*, April, 1920, p. 285.

The most fruitful theory of line spectra that has been developed is based on the nuclear model of the atom. Sir Ernest Rutherford and his students have shown by experiments on α-rays that the positive electricity in an atom does not occupy a volume larger than that of a sphere of radius 3.6×10^{-12} cm., and that the repulsive

force between nuclei obeys the inverse square law, at least down to distances of the order of magnitude of their dimensions.

N. Bohr (see a series of articles in *Phil. Mag.*, beginning in July, 1913) adopted the idea that the electrons in the atom revolve about the nucleus under the inverse square law of force, and assumed that when they revolve in a steady state the atom does not radiate energy. This, of course, is contrary to the prevailing theory of electricity, but, on the other hand, nobody has proved by direct experiment that an electron necessarily radiates energy simply because it is accelerated.

On the supposition that the electrons revolve in orbits that are circular, Bohr deduced the following expression for the force attracting an electron towards the nucleus:

$$\text{Force} = \frac{e^2}{a^2}\,(\mathrm{N} - \mathrm{S}_n - \varphi) = \frac{e^2}{a^2}\,\mathrm{F}$$

The first term represents the attraction of the nucleus for the electron, the second represents the repulsion on the electron due to other electrons in its own orbit, and the third, the force due to all the electrons in other orbits. (The functions S_n and φ may be found on pages 479–485, *Phil. Mag.*, Sept., 1913. e is the charge of the electron, a the radius of its orbit and N the atomic number of the chemical element).

Equating this force to the mass of the electron multiplied by its centripetal acceleration we have:

$$\text{Acceleration law} \quad \frac{mv^2}{a} = \frac{e^2}{a^2}\,\mathrm{F} \tag{1}$$

Evidently this law alone does not suffice to determine both the velocity, v, and the radius, a. Bohr, therefore, introduced a second law which may be stated as follows:

The angular momentum of the electron must equal $h/2\pi$, or some whole multiple of $h/2\pi$, where h is Planck's action constant. In equation form this becomes

$$\text{Momentum law} \quad mva = \frac{\tau h}{2\pi} \tag{2}$$

where τ is a whole number.

This law may be regarded as a generalization from experiment, in the sense that certain equations that can be deduced from it fit certain facts of spectrum analysis with very great precision, or it may be deduced (by making certain assumptions) from an equation occurring in the quantum theory, namely,

$$\int pdq = \tau h$$

where p and q are generalized coordinates (See William Wilson, *Phil. Mag.*, June, 1915, p. 795, and Arnold Sommerfeld, *Atombau und Spektrallinien*, Chapters 4 and 5, etc.).

To each value of τ (1, 2, 3, etc.) belongs a certain orbit, having a certain radius, a, and in which the electrons move with a certain velocity, v. The radii and velocities may be calculated, if we know the number of electrons in each orbit, for we have from (1) and (2)

$$a = \frac{\tau^2 h^2}{4\pi^2 e^2 m F}, \text{ and } v = \frac{2\pi e^2}{\tau h} F. \tag{3}$$

The third law in Bohr's theory deals with the radiation from an atom. Bohr assumes that if the atom passes from one stage of dynamic equilibrium, defined by the above equations to another state, also defined by the same equations (*i. e.*, if the numbers of electrons in the various orbits change), the atom radiates the difference between the amounts of energy it possesses in the two states. This difference may be estimated by calculating the total energy W (potential + kinetic) due to the motion and relative position of the electrons and the nucleus. Using the relativity expression for the kinetic energy, W has the form

$$-\mathrm{W} = \Sigma m_0 c^2 (1 - \sqrt{1 - \beta^2}) \tag{4}$$

where β is the ratio of v to the velocity of light, c, and v is given by equation (3).

In order to determine the frequency of the radiation (assumed monochromatic) Bohr adopted an idea in Planck's quantum theory, namely, that the frequency ν, multiplied by h, equals the energy radiated. This gives us the equation

$$\text{Frequency law} \quad h\nu = W_2 - W_1. \qquad (5)$$

The mechanism by means of which the radiation takes place is unknown. The laws are purely descriptive.

In the case of a single electron revolving about a nucleus (hydrogen and ionized helium, for instance) the equations deduced from the above laws agree with experiments to an extraordinary degree of precision. (See among other articles, Paschen, *Ann. d. Phys.*, 50, 1916 (901).)

Applied to X-rays, Bohr himself showed that they give the right order of magnitude of the phenomena. According to the theory (an idea originally suggested by Sir J. J. Thomson) X-rays are produced after a cathode particle has knocked an electron out of its position in the atom by the return of an electron to fill the vacancy. This electron may come from one of the orbits further out, or perhaps from outside the atom altogether.

In order to calculate the frequency of the X-rays emitted in a particular case we must know the numbers of electrons in the various orbits. So far the present theory does not determine these, and we are left with two modes of procedure. Either we must choose the numbers that best fit a great many observed frequencies, or we must seek to find out the distribution of the electrons from other phenomena.

Debye, Kroo, Sommerfeld, Vegard and others have calculated X-ray frequencies by arbitrarily assuming distributions of the electrons. Sommerfeld's calculations for the α_1 line in the K series is perhaps the most accurate (*Physik, Zeit.* 1918, p. 297). According to the general theory the inner orbit ($\tau = 1$) is associated with the K series and the Kα line is produced when an electron falls from the second orbit to fill a gap in the first. On the assumption that the inner orbit originally had three and the second orbit

($\tau = 2$) 9 electrons, Sommerfeld computed the values in the following table:

$K\alpha_1$ Lines. Frequency Divided by Rydberg Constant

Chemical Element	Magnesium	Bromine	Tin	Tungsten
Atomic number	12.	35	50	74
Calculated	92.3	880	1870	4400
Observed	92.1	880	1871	4379

It appears, therefore, possible to choose a distribution of electrons such that the frequencies calculated from the theory agree with some of the observed values to a considerable degree of precision.

The explanation of absorption appears to be much more difficult than that of emission. The idea underlying "critical absorption" may be stated as follows:

If the frequency of vibration is such that the energy ($h\nu$) in an X-ray pulse equals or exceeds the energy required to remove an electron from one of the orbits in an atom, the X-rays can and do remove electrons from that orbit of the atoms they pass through. The energy required to do this comes from the X-ray beam, and there is, therefore, an increased absorption for X-rays of higher frequency than a certain critical value over that for X-rays of lower frequency.

On this view it becomes possible to compute a critical absorption frequency by calculating the difference between the energies in the atom before and after the removal of an electron.

The writer presented a set of calculations of this kind to the American Association for the Advancement of Science at its meeting in St. Louis last December (*Science*, May 21, 1920). Instead of arbitrarily assuming a distribution of electrons he took the distribution suggested in the Lewis-Langmuir theory of a static atom to explain chemical phenomena. This theory divides the volume of the atom into spherical shells. The innermost shell contains two electrons, the next shell contains two layers of eight electrons each, etc. Translated in terms of the dynamic atom, this means that the inner orbit ($\tau = 1$) contains two electrons, the next two orbits (for each of which $\tau = 2$) contain 8 electrons each, etc.

This amounts to saying that the numbers of electrons in the orbits correspond to the periods in the atomic numbers

2, 8, 8, 18, 18, 32.

As these numbers may be written

$$2 \times 1^2, 2 \times 2^2, 2 \times 2^2, 2 \times 3^2, 2 \times 3^2, 2 \times 4^2,$$

the law connecting the number, n, of electrons in an orbit with the orbit's quantum number, τ, may be expressed by the equation

$$\text{Distribution law} \quad n = 2\tau^2. \qquad (5)$$

With this distribution of electrons I have calculated the K critical absorption frequencies (each divided by the Rydberg fundamental frequency) for some of the chemical elements (taken at atomic number intervals of about 10). The following table contains the values.

TABLE 15

K CRITICAL ABSORPTION FREQUENCIES

Frequencies Divided by Rydberg Constant, $\frac{\nu}{\nu_\infty}$

Chemical Element	Atomic Number	Calculated (Uncorrected)	Observed	Calculated (Corrected)
Aluminium	13	116.7	114.8	118.5
Phosphorus	15	157.5	158.4	163.9
Manganese	25	479.2	482 4	500.8
Bromine	35	988.2	993.5	1000.5
Rhodium	45	1696.0	1711.0	1717.3
Caesium	55	2584.0	2648.0	2643.0
Terbium	65	3752.0	3809.0	3812.0
Tungsten	74	5067.0	5118.0	5118.0

The third column in the table contains values calculated without using the correction (ϕ above) for the influence of different orbits on each other, the fourth column contains the observed frequencies, and the fifth the calculated values with an (approximate) correction for the mutual influence of neighboring orbits. The observed values have been taken from measurements made in our own laboratory (see Table 2) for manganese and all the elements of higher atomic number, while those for aluminium and phosphorus come from Fricke's experiments. As a rule the observed data lie between the two sets of calculated values, *i. e.*, within the corrections for the mutual influence of orbits on each other. The fair agreement between theory and experiment becomes more striking when we remember that none of the numerical magnitudes used in making the computations come from measurements on X-rays themselves. Everything has been taken from other branches of physics.

This distribution of electrons in the orbits gives fairly accurate values for the frequencies of a few of the emission lines, but does not always represent the facts.

The values in Table 15 were calculated on the assumption that all the orbits lay in the same plane. I have also calculated the ratios ν/ν_∞ for the case where the orbits lie in parallel planes with their centres on a straight line through the nucleus perpendicular to the planes. This gives a volume distribution of electrons. (See a note by Duane on the Structure of Atoms in the *Nat. Acad. Proc.*)

In this case the orbits are held apart by the mutual repulsion of the electrons in them. I have used an approximate expression only for the repulsive force. The approximation, however, comes in a correction term that is subtracted from the main term giving the value of the ratio ν/ν_∞.

Column 3 in Table 16 contains the calculated and column 4 the observed values.

Column 5 in Table 16 contains values calculated on the assumption that each of the orbits is split into two orbits, one outside the other. This gives a distribution more in accord with the idea of spherical shells, each containing two layers of electrons. Except for atoms of very low atomic numbers the agreement between theory and observation is fair.

TABLE 16

K CRITICAL ABSORPTION FREQUENCIES

Chemical Element	Atomic Number	Frequencies Divided by Rydberg Constant ν/ν_∞		
		Calculated	Observed	Calculated
Magnesium	12	105.6	95.8	103.2
Sulphur	16	187.6	181.8	187.4
Calcium	20	298.1	297.5	297.7
Iron	26	523.5	523.8	521.0
Selenium	34	927.2	930.8	923.3
Molybdenum	42	1460.0	1474.0	1454.0
Tin	50	2146.0	2148.0	2125.0
Cerium	58	2933.0	2970.0	2918.0
Dysprosium	66	3918.0	3948.0	3896.0
Tungsten	74	5068.0	5118.0	5043.0
Lead	82	6431.0	6463.0	6404.0
Uranium	92	8535.0	8477.0	8468.0

Any one of the above considered arrangements of orbits containing electrons distributed according to what we may call the

chemical distribution appears to give the observed values of the K critical absorption frequencies to within a few per cent.

In looking for explanations of the small differences between the calculated and observed values we must remember that the calculations are only approximate and that the influence of elliptic orbits, chemical bonds between atoms, etc., have not been taken into consideration.

Sommerfeld (*Atombau und Spectrallinien*) has published a theory of the fine structure of certain lines in the visible spectrum, which is based on the idea that in some atoms the orbits may be ellipses instead of circles. Applying the quantum law

$$\int pdq = \tau h$$

to elliptic orbits he finds that the shape (eccentricity) of an ellipse is determined by the value of the whole number, τ. The energy of an electron, calculated from the relativity formula which takes account of the change of mass with velocity, turns out to be slightly different for an elliptic orbit from its value for a circular one. Hence the frequency of a line in the spectrum due to atoms with elliptic orbits must be slightly different from the frequency of the line due to atoms with circular orbits. The theory seems to explain the structure of certain lines in the visible spectrum with considerable precision.

Applying the theory to X-ray spectra he deduced a formula for the difference in frequency between the two strong lines in the K series, which is the same as the difference in frequency between certain pairs of lines in the L series and also the same as the difference in frequency between the two strong L critical absorption frequencies. (See page 385.) The formula contains an undetermined constant, and it is possible to choose a value for this constant such that the formula represents the facts fairly well.

This theory with a single L orbit which may be either a circle or an ellipse does not explain the presence of the third L critical absorption frequency. Two such L orbits would indicate four critical absorption frequencies.

If the theory of elliptic orbits is correct and some of the atoms of a chemical element have amounts of energy that differ from the energy of other atoms of the same element, there must be corresponding differences in all the X-ray frequencies. In other words critical ionization, critical absorption, quantum and emission wave-

lengths must be complex. The lines, etc., must have a large but finite number of components closely packed together.

The theory of X-radiation explains quite well the facts mentioned on page 386. According to the conception of critical absorption given above if the incident X-rays have frequencies equal to or greater than the critical absorption frequency, they have energy ($h\nu$) enough to lift an electron from, say, the K orbit, and carry it out of the atom, that is, they can ionize the atoms to greater extent than if their frequencies lie below the critical value. Hence the critical absorption frequency should equal the critical ionization frequency (A, page 386).

According to the theory the α lines in the K series are produced by electrons falling from the second to the first (or inner) orbit, and the β lines to electrons falling from the third to the first orbit. The γ line is due to electrons falling from the fourth orbit and from *all orbits outside it* to the first. Hence the γ line must be complex and have an average, or centre of gravity frequency below that of its shortest possible component. This average frequency must, therefore, lie below that of the critical absorption frequency, which agrees with B (page 386).

The theory indicates that the quantum frequency must equal the critical absorption and critical ionization frequencies, since each, multiplied by h, represents the amount of energy required to lift an electron out of its orbit and carry it outside of the atom (C, page 386).

Bohr's theory explains in an obvious manner (Kossel) why an emission frequency (ν_α) should equal the difference between two critical absorption frequencies (ν_{a_1} and ν_{a_2}). If W is the total energy of the atom in its natural state with all its electrons in place, and W_1 and W_2 are the quantities of energy possessed by the atom (and electron) when one electron has been removed from the first or second orbit, respectively, the critical absorption frequencies are given by the equations

$$h\nu_{a_1} = W_1 - W \quad \text{and} \quad h\nu_{a_2} = W_2 - W.$$

The emission frequency (multiplied by h) of the line produced when an electron falls back from the second to fill a gap in the first orbit, equals the difference in energy between a state in which an electron is missing from the first orbit and that in which an electron is missing from the second orbit, *i. e.*,

$$h\nu_a = W_1 - W_2.$$

Hence

$$h\nu_\alpha = h\nu_{a_1} - h\nu_{a_2}$$

or the emission frequency equals the difference between the two critical absorption frequencies. (See tables on page 387.)

If some atoms have elliptic and others of the same chemical element have circular orbits, and the critical absorption frequencies are complex (as explained on page 405), the above law applies strictly to one kind of atom only.

Theories or "principles of selection" have been developed (Bohr, Rubinowicz, Sommerfeld) according to which transfers of electrons between certain pairs of orbits cannot take place (at least in cases where the atoms are not subjected to strong electric forces).

The reasoning starts out with an attempt to reconcile or unite the quantum theory with the older classical wave theory. It postulates that the decrease in the angular momentum $\frac{\tau h}{2\pi}$ in an atom when it changes from one state to another must equal the moment of momentum which may be ascribed to the spherical wave system radiated out from the atom during the change.

According to the theory the quantum number τ which is associated with the angular coordinate φ (not that associated with the radial coordinate, r) that fixes the position of a moving electron cannot change by more than unity. This limits the number of transfers that can take place, and, therefore, the number of lines that can appear in the emission spectrum.

If we apply this theory to X-rays we find that transfers of electrons can take place from either of the L orbits to the K orbit, giving rise to both the $K\alpha_1$ and $K\alpha_2$ lines, and these appear in the spectrum. (See Table A, page 387.) The third L orbit is not included in this present theory.

In the case of the L series (see Table B, page 387) the transfers represented by the $La_1 - Ma_1$, $La_1 - Ma_2$ and $La_2 - Ma_2$ should occur according to the theory, and, as a matter of fact, the corresponding lines $L\alpha_1$, $L\alpha_2$ and $L\beta_1$ are well known lines, and their frequencies agree perfectly with the theoretical values. Theoretically the transfer $La_2 - Ma_1$ should not occur, and no line corresponds to it in observed spectra. The transfers $La_1 - Ma_3$ and $La_2 - Ma_3$ should occur, but lines corresponding to them have not always been observed. The remaining transfers represented in the table are not covered by the theory.

A theory by which the relative intensities of spectral lines may be calculated has been suggested by Sommerfeld (*Atombau und Spektrallinien*, Chapter 6). He applied the quantum laws to orbits that do not lie in the same plane. He assumed that the integral equation $\int pdq = \tau h$ holds for each of the three coordinates of an electron moving in an orbit, the plane of which may be inclined at an angle to a fixed direction in the atom. It appears from the theory that the plane can have any one of several positions, and that the number of these positions depends upon the value of τ associated with the angular (but not the radial) coordinate of the electron. On the assumption that each position of the plane is equally probable the theory gives a method of estimating the relative intensities of spectral lines, for, if τ is large, there are more positions that the plane of the orbit can occupy, and therefore a greater chance for transfers from that orbit to take place.

According to a theory of Bohr's one of the positions of the plane is dynamically impossible, which changes somewhat the estimate of relative intensity.

If we apply the theory to the α lines in the K series of X-rays we find that according to it the ratio of the intensity of α_1 to that of α_2 is either $\frac{3}{2}$ or $\frac{2}{1}$. The actual ratio determined from ionization curves for rhodium and tungsten (Duane and Hu, Duane and Shimizu) is 2.0.

Applied to the two α lines in the L series the theory gives $\frac{4}{3}$ or $\frac{3}{2}$ as the ratio of their intensities, whereas from measurements on ionization curves for tungsten (Duane and Patterson) the ratio appears to be 10.

In general the theory of radiation discussed in this summary seems to represent a great many details of X-ray spectra with considerable precision and accuracy. In some cases, however, it does not in its present form agree with the facts.

No satisfactory explanation both of the production of secondary corpuscular rays and of such phenomena as interference has been given by one and the same theory, without making a number of special hypotheses.

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Professor of Physics, Columbia University,

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PROBLEMS OF X-RAY EMISSION

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Stanford University, California

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By David L. Webster, Stanford University, California

CONTENTS

* This monograph is the second of a series which when complete will form the report of a committee of the Division of Physical Sciences of the National Research Council. This committee on X-ray spectra consists of the following members: William Duane, Harvard University, Chairman; Bergen Davis, Columbia University; A. W. Hull, General Electric Research Laboratory; D. L. Webster, Leland Stanford Junior University.

INTENSITY OF EMISSION OF X-RAYS AND THEIR REFLECTION FROM CRYSTALS

By Bergen Davis

TOTAL EMISSION OF ENERGY FROM X-RAY TUBES

From the very beginning after the discovery of Röntgen rays there was great interest in and discussion of the new phenomenon.

While the possibility that the new radiations might be corpuscular in nature was given much consideration, the consensus of opinion among physicists was that they were not corpuscular but of the nature of electromagnetic waves or pulses emitted from the target at the impact of the cathode rays. This view was early formulated by Sir George Stokes. Whatever might be the nature of the radiation, it must be energy in some form and many attempts were made to detect this energy and to measure it.

This résumé will be divided into two parts. The one concerning itself with the less accurate experiments with the gas-filled X-ray tube and the unsatisfactory sources of high potential available at that time. The other will consider those later investigations undertaken after the development of the hot filament tubes of the Coolidge type and the electron rectifying tubes that are now so effective in X-ray experiments.

Earlier Experiments

Only a cursory view will be taken of those earlier measurements of X-ray energy. The phenomenon was so new, the conditions for the production and regulation of the radiation so little understood that the results necessarily cannot now be considered as accurate.

The principal sources of error were of two kinds: (*a*) the high potential source for exciting the tubes. In the earlier work on X-rays, the usual source of high potential was the induction coil operated by some form of interrupter as the mechanical break, the mercury turbine and later the Wehnelt electrolytic interrupter. These methods gave such variable voltage impulses, that it was difficult to measure accurately either this variable voltage or the still more variable current passing through the tube. (*b*) The other great source of inconstancy was the gas-filled tube. Both the potential and current depended not on the apparatus but on the vacuum conditions in the tube. To keep this constant or to regulate it was a matter of great difficulty.

An early investigation of total emission was that of Dorn.[1] The energy of the emitted rays was measured by the heat developed by their total absorption in strips of metal, the amount of heat being measured by the expansion of the strips. The total energy emitted from the tube in the form of X-rays varied from 0.85×10^{-5} to 3×10^{-5} gram cal. per second.

Another investigation of interest is that of M. Wien.[2] The efficiency of X-ray emission was determined in this case. The target was so arranged that the heat produced by the impact of the cathode rays could be measured by a calorimetric method. The energy emitted was measured by absorbing it in both a thermopile and a bolometer. The potential across the tube was maintained about 59000 volts. The ratio of X-ray energy to the energy of the cathode rays was about 1.1×10^{-3} to 1.3×10^{-3}. Using these results Wien attempted to calculate the pulse length of the X-rays and obtained a value of 1.15×10^{-10} cm. We now know that the shortest waves emitted by a tube at 59000 volts are about 2.3×10^{-9} cm. in length.

E. Carter[3] found an efficiency of 1.07×10^{-3}. The efficiency increased with increasing atomic weight of the target.

E. Angerer[4] obtained an efficiency of 2×10^{-3}. The efficiency increased with increasing voltage.

Other attempts were made to measure the efficiency by means of the ionization produced by the X-rays. Among others might be mentioned the experiments of Rutherford and McClung[5] and Eve and Day.[6]

The dependence of the total emission on the atomic weight of the anticathode was investigated by Kaye.[7] The intensity of X-ray emission was measured by an ionization method. The tube was so arranged that a number of metals placed on a carrier could be moved into place and bombarded by the cathode rays. The conditions as to current and voltage were kept as constant as possible throughout. The result indicated that the intensity was proportional to the atomic weight of the metal forming the target. An improvement in the means of studying total emission was made in 1913 by R. T. Beatty.[8] The principal object in this research was to ascertain how the intensity of the X-rays depended on the velocity of impact of the cathode electrons against the target. Homogeneous cathode rays were obtained by drawing the non-homogeneous rays out into a spectrum and allowing the rays of a

given velocity to pass through a small hole and strike the target. The X-rays were emitted through a thin partition into a long ionization chamber containing methol iodide. The chamber was sufficiently long to permit of the complete absorption of the X-rays. The intensity was found to be proportional to the fourth power of the velocity of the cathode rays. It was also proportional to the atomic weight of the target. The intensity was found to increase more rapidly in some cases at the velocity at which the characteristic rays are produced. This was notably the case with copper. The following relation was found to hold.

$X = .58A\beta^4$, where A is the atomic weight of the target and $\beta = v/c$, and X = energy emitted as X-rays. He deduces the following relation between the X-ray energy and the cathode ray energy N.

$X/N = 2.54 \times 10^{-4} A \beta^2$.

Later Experiments

In recent years X-ray research has been placed on a new plane of accuracy by the development of new apparatus and the discovery of new phenomena.

(*a*) The invention of the new type of X-ray tube known as the Coolidge tube was one of these great improvements. This tube permits of the accurate control of the potential and current through the tube, each independent of the other. This was quite impossible with the gas-filled tube.

(*b*) The improvements in the methods of producing high vacua together with the perfection of the tungsten filament as a source of thermo-electrons resulted in the development of very efficient electron valve tubes for the rectification of high potentials. One of the most successful of these is the kenotron developed by the General Electric Company.

(*c*) The discovery by M. Lane of the diffraction (reflection) of X-rays by crystals and the application of this discovery in the X-ray spectrometer by W. H. Bragg marks a new departure in X-ray research.

One of the earliest investigations using the standard Coolidge X-ray tube with a tungsten target was that of Rutherford.[9] The emission at three voltages, 48, 64 and 96 kilovolts was compared. The radiated energy was found to be nearly proportional to the

square of the voltage, increasing perceptibly at the higher voltage.

From each element used as a target there are two types of radiation emitted. The general radiation and the characteristic. The characteristic radiation appears at a voltage that is fixed and characteristic of the target. This voltage is approximately proportional to the square of the atomic number of the target. The general radiation is produced at all voltages.

A question of some interest and importance from the point of view of X-ray theory is whether the total emission suddenly increases when the characteristic voltage is exceeded. This point, together with some others, was investigated by C. S. Brainin.[10] A special X-ray tube was prepared having a Coolidge tungsten filament. The target was so constructed that six different metals could be rotated into position and bombarded by the cathode rays under precisely similar conditions. The high potential current was rectified by a kenotron set and stored in a large condenser. The metals investigated were Pt, W, Mo, Co, Cu and Ag. The X-rays passed from the tube through a thin mica window and were totally absorbed in a long ionization chamber. In general it was found that the intensity was nearly proportional to the square of the voltage but not over the whole range except in the case of molybdenum. Both copper and cobalt showed an emission proportional to the square of the voltage until the characteristic voltage was reached, at which point there was a decided increase in the emission. Silver showed an anomalous effect. When the characteristic voltage was reached there was a decided decrease in rate of total emission.

Duane and Shimizu[11] have investigated the emission from Fe (26), Co (27), Ni (28) and Cu (29). The numbers in the brackets are atomic numbers. The voltage ranged from 19000 to 32000 volts. The conclusion was reached that the emission is proportional to atomic number and not to atomic weight. The results differ somewhat from those obtained by Brainin for copper and cobalt over the same range of voltage. The difference arises perhaps from the fact that Duane and Shimizu did not have total emission. The characteristic rays were almost entirely absorbed by the glass walls of the tube. At voltages below the critical voltage the radiation from copper was found by Brainin to be greater than from cobalt in agreement with Duane and Shimizu.

But above the critical voltage cobalt emitted the greater energy, indicating that the characteristic emission from cobalt is probably more intense than that from copper. The point needs further investigation.

The earlier work on total emission was principally concerned with the efficiency of production of X-rays,—the ratio of the energy emitted as X-rays to that supplied to the tube. This matter as well as the dependence of the emission on voltage has been investigated by P. T. Weeks.[12] The source of potential and current was a high potential transformer. The high potential current was rectified by a synchronous rectifier such as is used by physicians. The energy supplied to the tube was measured by immersing the tube in oil and noting the rise in temperature. The emitted X-ray energy was totally absorbed in and measured by a bolometer. The emitted energy was found to be proportional to the *cube* of the voltage, current constant. The efficiency increased with increasing voltage. It was found to be proportional to the *square* of the voltage.

The result obtained by Weeks that the total emission increases as the *cube* of the voltage and not as the *square* as obtained by Beatty and Brainin and others, is undoubtedly due to the effects of absorption. The X-ray tube was immersed in oil in a box. The rays had to penetrate not only the glass of the X-ray tube but a certain thickness of oil and also the walls of the container. Since the radiations at lower voltages are much more strongly absorbed than those at higher voltages, their intensity was much diminished. The law of dependence on voltage so obtained does not at all represent that of actual emission inside the tube. The same remarks apply to a less extent to the experiments of Beatty and Brainin. The rays in their experiments passed through thin films, but the voltages were so low that a considerable part of the radiations were absorbed in these thin films. As an illustration of this the rays in Brainin's experiments passed through a mica diaphragm 0.001 cm. thick. A simple calculation shows that about 20% of the radiations at 12000 volts are absorbed in such a film of mica. It follows that if the results indicate that the observed energy is proportional to the *square* of the voltage, the actual increase inside the tube must have been at a smaller rate than the square.

Weeks gives a table of efficiency obtained by other experimenters that is of some interest and is here reproduced.

Observer	Method	Potential	Efficiency
Wein	Bolometer	58.7 k.v.	0.0014
Wein	Thermopile	58.7	0.0018
Angerer	Bolometer	Low	0.0004
Carter	Bolometer	59	0.00012
Hoepner	Thermopile	63	0.00029
Eve and Day	Ionization	11 cm. gap.	0.0001
Rutherford and Barnes	Ionization	48	0.00059
Beatty	Ionization	48	0.0019

A knowledge of the laws controlling the emission of X-rays is both of theoretical and practical value. Increased efficiency of production is very important in the practical application of the rays in the arts. It is not clear how great advance in this direction can be expected. Some increased efficiency would result in the use of a metal of higher atomic weight as a target. It is perhaps worth while to call attention to a means of obtaining partially homogeneous rays of any degree of hardness (mean wave-length) without the presence to a great extent of the more injurious softer rays of longer wave-length.

This may be accomplished by depositing a thin film of a very refractory metal of high atomic weight such as tungsten, platinum or uranium on a backing of a metal of low atomic weight such as chromium. The electrons while they have a high velocity will produce rays of short wave-length in the thin film. When they have decreased in velocity sufficiently to produce soft X-rays they will have passed through the film and make impact with the atoms of chromium. The radiation from the chromium, however, is very weak compared to that from a target of high atomic weight. The energy wave-length curve of the radiation from such a target would show a sharp peak falling to a small value on the long wave-length side.

The real aim of the study of X-ray emission is not the total emission appearing outside the X-ray tube but rather the emission from a single atom when impacted by a swiftly moving electron. The object of physical research is the nature of radiation itself and a detailed knowledge of the structure of an atom that can emit such radiation. A matter of prime importance before any theory of X-ray emission can be developed and tested is a knowledge of the decrease of velocity of electrons as they penetrate down into the target. At best the observed radiation is the sum of the emission

excited by electrons having different velocities at different depths within the target. A complete knowledge of this velocity decrease as well as the absorption of the radiation as it passes out through the surface from any depth is essential before the emission per atomic impact can be determined.

INTENSITY OF THE CHARACTERISTIC (LINE) SPECTRA OF X-RAYS

An important object of physical research is a knowledge of the structure of the atom and the mechanism of all atomic radiations. The study of the radiation from atoms seems to promise a fruitful source of such knowledge. There are at least two properties of atomic radiation that may be studied: their frequencies, and the intensities of emission at each frequency. The subject of spectral line intensity has not been extensively investigated even in the case of the visible radiations, and much less so in the case of X-radiation.

The subject naturally separates into several divisions:

(*a*) The relative intensities of the several lines of any one series, for example, the relative intensities of the γ, β and the two α lines of the K characteristic of the elements.

(*b*) The relative intensities of the lines in the L and M characteristic that manifestly belong to the same series.

(*c*) The relative intensities of corresponding lines in different series.

(*d*) The intensity of emission at a given frequency from a single atom. It is possible that this is a quantum corresponding to the frequency.

(*e*) The dependency of the intensity of any frequency on the atomic number or other property of the atom.

(*f*) The dependence of the emitted energy on the energy of the cathode rays exciting the radiation.

Here is a large field of research, an undiscovered country, so to speak, which investigation has hardly yet explored. The investigation of energy of emission is, however, one of some difficulty. A considerable equipment of apparatus is necessary for accurate research in this field.

(*a*) A reliable source of X-rays. This is now pretty well supplied by the hot cathode, gas-free tube of the Coolidge type.

(*b*) A constant source of high unidirectional electrical potential. Probably the best possible source of high potential is a large number of storage cells. Next to this an alternating current transformer

with electron valve tube rectifiers together with a suitable condenser. Such a source of constant direct high potential has been described by Dr. A. W. Hull.[13]

(*c*) The X-ray spectrometer which was devised by Bragg shortly after the discovery of crystal reflection by Laue. Various types of these have been devised, such as the vacuum spectrometer for the measurement of wave-lengths as used by Mosely and Darwin, de Broglie, Siegbahn and others. The ionization spectrometer of Bragg is especially suited to the study of the intensity of line emission.

(*d*) The properties of the crystal used in obtaining the spectrum. Crystals differ in their power of reflection at various wave-lengths. This property was early observed and studied by W. H. Bragg.[14] The reflection depends in a marked degree on the absorption coefficient of the crystal for any particular frequency. Thus Bragg measured the reflection of some of the L radiations of platinum by a rock salt crystal and by a zinc-blende crystal. Certain lines are strongly reflected by rock salt and poorly reflected by zinc-blende. It was found that those radiations that were poorly reflected were strongly absorbed in the crystal. A source of error in crystal reflection is the discontinuities in the parallelism of the reflecting planes of the crystal. Bragg has called attention to the fact that this is a common defect of rock salt crystals.

The intensity differences of the various spectral lines are observable in experiments with the photographic spectrometer. Some lines appear faint and others strong. The photographic plate, however, is not well suited to the accurate measurement of line intensity.

One of the earliest investigations of the relative intensities of X-ray spectra and their dependence on voltage is that of D. L. Webster.[15]

A Coolidge tube having a rhodium target was used as a source of radiation. The rays were reflected from a calcite crystal into the chamber of an ionization spectrometer. The α and β lines were found to appear simultaneously at the critical characteristic voltage. The intensities of both the α and β radiations were found to increase rapidly with the voltage. The ratio of intensities of the two radiations was constant and independent of the voltage.

A study of the lines of the L_1 and L_2 series of platinum has been made by Webster and Clark.[16]

The intensities of the lines increase with the voltage by the

same law as that found for the K radiation from rhodium. The ratio of intensity of the lines of any one series remains constant and independent of the voltage.

A detailed study of the α and β, K radiations of molybdenum and palladium was made by Wooten[17] in 1917. Two separate tubes were used each containing a target of one of the metals investigated. The rays were reflected from a calcite crystal into a long ionization chamber containing methyl-iodide. They were nearly completely absorbed. A plot of the curves of intensity against the *square* of the voltage gave a straight line except near the beginning where they were concave upward. The ratio of the intensities was constant and independent of the voltage as found by Webster. The observed ratio of the α to the β radiation was 3.99 for molybdenum and 5.28 for palladium. The coefficient of absorption of these rays in glass was determined at the same time and a correction made for their absorption in the walls of the X-ray tubes. The corrected ratios then became 5.55 and 6.25, respectively. These latter values then would be the true values of the ratios of intensity inside the tube as emitted from the target *provided* the reflectivity of the crystal were the same for all wave-lengths. Attention is called to the fact that such ratios even when corrected for absorption and reflectivity would not be the true ratio of their emission from the atom. The cathode electrons penetrate to various depths and the radiations are subject to absorption as they pass out through the material of the target. The ratio of the energy of emission of each atom when excited by electron impact is the real quantity which it is desirable to determine.

A descriptive theory of energy of emission of line spectra has been given by Bergen Davis.[18] The theory makes no special assumptions as to the mechanism of radiation. It takes into account the decrease of velocity of the electron in the target and the absorption of the rays from various depths within the target. The assumption is made that the interchange of energy between the impacting electrons and the radiating electrons of the atom is *radial* with respect to the nuclear center of the atom. *The expression obtained contains no arbitrary constants.* The two constants involved may be determined by independent experiment. The expression agrees closely with the observed results even giving the change in curvature as the voltage is first increased beyond the critical characteristic voltage.

The frequencies of the line spectra depend on the atomic number. It may be expected that their intensities will also be found to be a property of the atomic number. There is perhaps no more promising field of research than the energy of emission of the characteristic line spectra of the elements.

INTENSITY OF REFLECTION OF X-RAYS FROM CRYSTALS

The efficiency of reflection of X-rays from crystals is not only of great interest, but a knowledge of the laws of reflection is of considerable practical importance in the investigation of the energy distribution in the continuous X-ray spectrum, and also of the intensity of characteristic line emission.

Some consideration has been given to this matter more especially from the point of view of the theory of such reflection.

The original discussion by M. Laue concerns itself primarily with the position of the Laue "spots" and not to the intensity of reflection, and will not be further referred to here.

A theory of X-ray reflection that has attracted some notice is that of Darwin.[19] This theory proceeds on the assumption that the reflection has its origin in the scattering of the radiation by the electrons of the atoms of the crystal. Use is made of the law of scattering of radiation derived by Sir J. J. Thomson, namely, that the energy scattered is proportional to $\left(\frac{e^2}{mc^2}\right)^2$. This scattered energy from electrons in the successive crystal planes destructively interferes excepting in one direction, depending on the wave-length, the angle of incidence and the crystal spacing. In one particular direction there is reinforcing interference. The electrons contributing to the reflection are considered to be grouped quite near the atomic nuclei. No attempt is made by Darwin to specify this grouping. The width of the space occupied by the electron is considered to be small compared to the distance between planes. The rays as they penetrate the crystal diminish in intensity due to two factors: the scattering and the absorption. It is pointed out by Darwin that in case of a perfect crystal, the decrease due to absorption is probably small compared to the much greater effect of the scattering. However, it is pointed out that in case of an imperfect crystal the absorption plays an important part in the dissipation of the rays.

Proceeding on the general lines referred to above and introducing the polarization factor $(1 + \cos^2 2\theta)$ and also the factor allowing

for the effect of the heat motions of the atoms, Darwin derives an expression for the case of an imperfect crystal which may be conveniently written:

$$R = A\,\frac{\lambda^3(1+\cos^2 2\theta)}{2\sin\theta\cos\theta}\,\frac{N^2}{4\mu}\,f^2\,e^{-\frac{\beta\sin^2\theta}{\lambda^2}}$$

where A is a constant, N the number of electrons per unit volume, μ the coefficient of absorption of the rays in the crystal $f = \frac{e^2}{mc^2}$. The term $e^{-\frac{\beta\sin^2\theta}{\lambda^2}}$ is the heat motion factor of Debye.

A consideration of the physical process involved in the reflection makes it evident that the reflection will depend on the distribution of the electrons in each reflecting plane and on the relation of this distribution to the distance between planes. If it is assumed that each molecule vibrates about its position of equilibrium due to the temperature agitation, the effective width of each plane will depend on the amplitude of such oscillation. The reflection may thus depend in a marked manner on the heat constants, the elastic constants and the temperature of the crystal. This temperature effect has been quite thoroughly treated by Debye.[20] The expression derived may be conveniently written in the form:

$$e^{-\frac{6h^2}{mk}\frac{T}{\sigma^2}\varphi(x)\cdot\frac{\sin^2\theta}{\lambda^2}}$$

where:

m = mass of the atom

h = Planck's constant

k = gas constant = 1.35×10^{-16}

σ = the temperature characteristic of the crystal. It denotes the temperature at which the substance of the crystal has a certain standard relation to its specific heat. $x = \frac{\sigma}{T}$. Debye evaluates the $\varphi(x)$. It varies from unity for $x = 0$ to 0.08 for $x = 20$. (*Loc. cit.*)

Debye deduces that the sharpness of the interference maxima is not affected by the heat motion. The intensity of the reflection and the space distribution of the intensity is affected by such motion.

The expression as written above is independent of the angle of reflection for any one order. Taking account of the order of reflection it may be conveniently written:

$$e^{-\beta \sin^2 \theta}$$

where the constant β is a function of the temperature, certain crystal constants and the wave-length.

The effect of the distribution of the electrons in the reflecting planes on the reflection has been considered by A. H. Compton.[21] The proceeding adopted is similar to that of Darwin. The reflection is due to scattering from electrons; the polarization factor $(1 + \cos^2 2\theta)$ and the temperature factor of Debye are introduced. The expression obtained for the reflectivity is similar to that of Darwin but contains the factor

$$\left[\int_a^b F(z) \cos \frac{4\pi z \sin \theta}{\lambda} dz\right]^2.$$

This function of z expresses the effect of the distribution of the electrons about the nucleus upon the reflection. Some special distributions are considered by Compton and it is shown that the distribution has a great effect on the intensity of the reflection.

The following form of reflectivity equation has been proposed and tested to some extent by W. H. Bragg.

$$R = \frac{C(1 + \cos^2 2\theta)}{\sin^2 \theta} e^{-\beta \sin^2 \theta}$$

This equation differs from that of Darwin by the factor $\tan \theta$. In discussing this equation Darwin points out that if the Bragg formula represents the phenomena it indicates a much more concentrated grouping of electrons than was assumed in the derivation of his equation. Compton does not consider that there is any possible grouping of electrons in the reflecting planes that will give the reflection the form proposed by Bragg.

The reflection of radiation of a given wave length at different orders has been investigated by W. L. Bragg.[22] He found the intensities of reflection at succeeding orders to be 100—20—7—3—1. This varies nearly as $1/n^2$. The Darwin equation, on the other hand, leads to the expectation that the reflection at the various orders should vary as $1/n$.

The whole subject is in need of much further study both experimental and theoretical.

The effect of the temperature of the crystal on the reflection has been observed and measured to a certain extent by W. H. Bragg (X-Rays and Crystal Structure). The results agree fairly well with

the predictions of the Debye formula. The intensity of the radiation decreased with rising temperature, the position of the line was also shifted owing to the change in grating space due to expansion of the crystal.

While the experiments just cited furnish information as to the Debye temperature effect, they contain no information as to the coefficient of reflection of the crystal. A determination of this quantity is of great importance for the progress of X-ray research.

An attempt to determine directly the coefficient of reflection has been made by A. H. Compton.[23] The measurements were made at only one wave-length, that of the α radiations from molybdenum. The radiation was reflected from a crystal mounted on a Bragg spectrometer in the usual manner. This reflected beam of nearly monochromatic rays was allowed to fall on a second crystal and the ratio of the intensity of the reflected ray to that from the first crystal was taken as the coefficient of reflection. An automatic integrating method was used to allow for the fact that some energy is reflected at small angles each side of the angle of the maximum.

The coefficient obtained for the reflectivity of calcite was 0.005 per degree and 0.023 per degree for rock salt.

Compton compares these results with the equation of Darwin, but introduces a term $\Delta\theta$ in the denominator. This $\Delta\theta$ is introduced to permit the comparison of the equation with his results obtained by the integrating method referred to above. According to Compton, the Darwin equation gives 0.04 per degree for rock salt and 0.058 per degree for calcite. The agreement is not very good. Compton does not state in detail, however, how he is able to calculate the absolute value of the Darwin equation, especially from what source he obtains the proper constants of the Debye temperature factor contained in the constant.

This would indicate a rather small coefficient of reflection, too small, in fact. A consideration of the phenomenon of reflection as actually observed indicates that the reflection at any one wave-length must be very good indeed. Thus in the reflection of the general X-radiation, the crystal reflects only that part of the energy lying between λ and $\lambda + d\lambda$. The extent of this region depends on the width of slits and their distance from the crystal. Now this $d\lambda$ is in general very small compared to the whole range of wave-lengths falling on the crystal, yet the energy reflected in this region $d\lambda$ is an appreciable part of the total emission, at all

wave-lengths. If the coefficient of reflection were as small as Compton's experiments would indicate, the reflected energy would be difficult of detection. The fact that it is very easy to observe indicates at once that the reflection must be very good. Another indication that the radiations are strongly reflected from a crystal is furnished by the experiments of Rutherford on the reflection of the gamma rays from radium. The intensity of the photographic traces leads to the conclusion that the intensity of the reflected beam was of the same order as that of the original.

A careful experimental investigation of the reflectivity of calcite has been in progress for some months at the Phoenix Physical Laboratory of Columbia University. A double X-ray spectrometer is used in these experiments. A nearly monochromatic beam of X-radiation lying in a region $\Delta\lambda$ is obtained by reflection of the general radiation from the first crystal. These monochromatic rays fall on a second crystal and are reflected into the ionization chamber. The coefficient of reflection is defined as the ratio of the intensity of this beam after the second reflection to its intensity before such reflection. The reflectivity is very large when the two crystal faces become exactly parallel. When this condition obtains all the radiation from the first crystal meets the second crystal at the proper angle for maximum reflection at the same setting.

The following table gives the results for the first order reflection from calcite.

Angle Degrees	Observed Coefficient	Calculated
3	0.257	0.267
4	0.235	0.2374
5	0.216	0.216
6	0.20	0.20
7	0.186	0.187
8	0.173	0.176
9	0.163	0.167

The third column gives the values obtained from Darwin's expression assuming the absorption to vary as $\lambda^{2.4}$. This value of the exponent of λ is less than has been found by experiment. The calculated curve rises rapidly at small angles. This rise at small angles becomes very great if μ is taken proportional to λ^3.

An interesting result was obtained in these experiments with two crystals. When the two crystals are so placed that their reflecting planes are exactly parallel it can be shown that every ray coming

from the first crystal will strike the second crystal at the proper angle for maximum reflection. Nevertheless when the second crystal is turned through a small angle some energy is still reflected. The angle at which there was some reflection was about one minute each side of the maximum. The curves plotted between the reflection and the small deviation of the second crystal have a constant area for the whole range of wave-lengths investigated.

THE DECREASE OF ELECTRON VELOCITIES ON PENETRATING THE TARGET

A knowledge of the laws of decrease of electron velocities of the cathode electrons penetrating into the target is indispensable to the formulation of any theory of X-ray emission. On account of its importance it is perhaps worth while to review here the small amount of work that has been done on this subject and to call attention to the need of further investigation.

It is evident that the X-rays are not only excited at the surface of the target but throughout that region within which the electrons still retain a considerable velocity. This has been shown experimentally by W. R. Ham[24] and L. D. Davey.[25] They both measured the mean depth of formation of X-rays within the target. The values obtained ranged from 2×10^{-4} to 6×10^{-5} cm., depending on the target and the voltage applied to the X-ray tube. The limit of penetration must of course have been considerably greater than this mean depth.

The decrease of velocity of swiftly moving electrons in matter has been theoretically treated by Sir J. J. Thomson.[26] It is shown that the law of velocity decrease should be

$$T_x^2 = T_o^2 - cx,$$

where T_o is the initial kinetic energy and T_x is the kinetic energy at any depth x. This law has been experimentally investigated by Whiddington.[27] The method employed was to measure, by the magnetic deflection, the velocity V_x of electrons after passing through a thin film with a known initial velocity v_o. Experiments were made with aluminum and gold foils. The theory of Sir J. J Thomson was confirmed. Whiddington expresses his results in terms of the velocities:

$$v_x^4 = v_o^4 - ax$$

The constant a was found to have the value of 7.32×10^{42} for aluminum and 25.4×10^{42} for gold. It does not appear to depend

in any simple manner on atomic weight, atomic number density or other property of the metal. Two methods of determining this constant directly by means of experiments with X-rays have been pointed out by Bergen Davis.[28]

The latter method is comparatively simple. A thin film of the metal to be investigated is deposited on a backing of some metal such as molybdenum that gives a characteristic radiation convenient to observe. The electrons will only cause the characteristic to appear when they have penetrated the film with sufficient velocity to excite such radiation. This critical velocity is already known for each element. The velocity at which they enter the film can be calculated from the voltage applied to the tube. The velocity is thus determined at each boundary of a film of known thickness.

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PROBLEMS OF X-RAY EMISSION

By David L. Webster

QUANTUM PHENOMENA IN THE GENERAL RADIATION SPECTRUM

The quantum theory, as first developed by Planck, was concerned primarily with heat radiation confined to about five octaves of the visible and infra-red spectrum. The phenomena of this region were not such as to suggest quanta of energy at all obviously; so in spite of the success of Planck's theory and the need for a constant of the dimensions of his *h*, which he pointed out in connection with the Wien displacement law, there were still many who doubted whether quanta had any real significance. Like atoms, to seem real, they needed to be detected individually.

The first opportunity for such detection was in the photo-electric effect, but there the experimental difficulties threw doubt on the results previous to those of Millikan. Even this spectral region, however, was not the most promising. The quantum energy must be proportional to its frequency—exactly so, according to Planck's reasoning—and the X-ray region was known to be 8 or 10 octaves higher in frequency than the ordinary ultra-violet. In X-rays, therefore, we might expect quanta to be most in evidence.

As applied to X-ray emission, the quantum theory would indicate that the energy of each cathode ray that can produce X-rays of a certain frequency must be at least as large as a quantum of the frequency produced. To test the law, we have only to measure the cathode ray energy and the X-ray frequency. To measure the cathode ray energy demands a source of uniform cathode rays, with a means of measuring either the potential drop that accelerates them, or their velocity as they strike the target. Since the cathode rays ordinarily used in X-ray work are far from uniform, this demands special apparatus. The ideal source of current for this purpose is a high tension battery. This was first used from 1898 to 1900 by J. Trowbridge,[1] who built a battery of 20,160 Planté cells for this purpose. But, unfortunately, no means were available during these years for sorting out the X-rays, which are far from homogeneous, even with cathode rays of a uniform speed, and there was no means of measuring their frequencies.

The use of more nearly homogeneous X-rays was first made possible by Barkla's discovery of characteristic rays. Such rays

were first used for this purpose in 1911 by Whiddington,[2] using secondary X-rays, and in 1912 by Beatty,[3] with primary. In both cases the cathode ray velocities were controlled and measured by a magnetic field. The X-ray frequencies, of course, were still unknown, but after these experiments the quantum law was assumed by many writers as a basis for calculating their frequencies.

The means of actually measuring X-ray frequencies was supplied by the invention of the spectrometer by the Braggs, who compared the characteristic frequencies calculated by the quantum law from the work of Whiddington and Beatty with the results of their wave-length measurements. This comparison indicated values for h about 30 or 40 percent above the values found in optical phenomena.[4] A great part of this difference, as a matter of fact, was largely due to the presence of general X-radiation along with the characteristic rays used, that made the latter difficult to detect, unless they were quite strong. The rest was due to the peculiar properties of characteristic rays, to be discussed later.

The Bragg spectrometer, however, made it possible also to overcome difficulties of this sort. Another invention of great value in such work was the Coolidge tube, which made the voltage regulation much easier than with any gas-filled tube. The spectrometer and Coolidge tube were used in 1915 by Duane and Hunt,[5] with Trowbridge's battery, for an accurate test of the quantum law as applied to the general radiation. They showed that when the potential is held constant and the ionization is plotted against frequency, the graph is everywhere continuous. It has a maximum at a frequency somewhat less than that given by the quantum law as applied to the cathode ray energy, but at the quantum law frequency itself, the graph of intensity comes down to the axis, striking it at a finite slope, and above this frequency no rays are detected. Thus the discontinuity at the quantum frequency is not in the intensity itself, but in its first derivative with respect to frequency.

In practice, of course, the ionization was actually plotted against wave-length or glancing angle, rather than against frequency. These graphs may be called "spectra."

Another type of graph, called by Wagner an "isochromat," is obtained when the frequency used is held constant, and the intensity is plotted against the potential. This graph is also continuous, with zero intensity up to the potential calculated by the

quantum law, where it leaves the axis with a finite slope. Above that potential the intensity seems to increase, apparently without a limit. Graphs of these two types, to which we shall have to refer again in connection with characteristic radiations, are shown in Figures 1 and 2, the former taken from a paper by D. L. Webster[6]

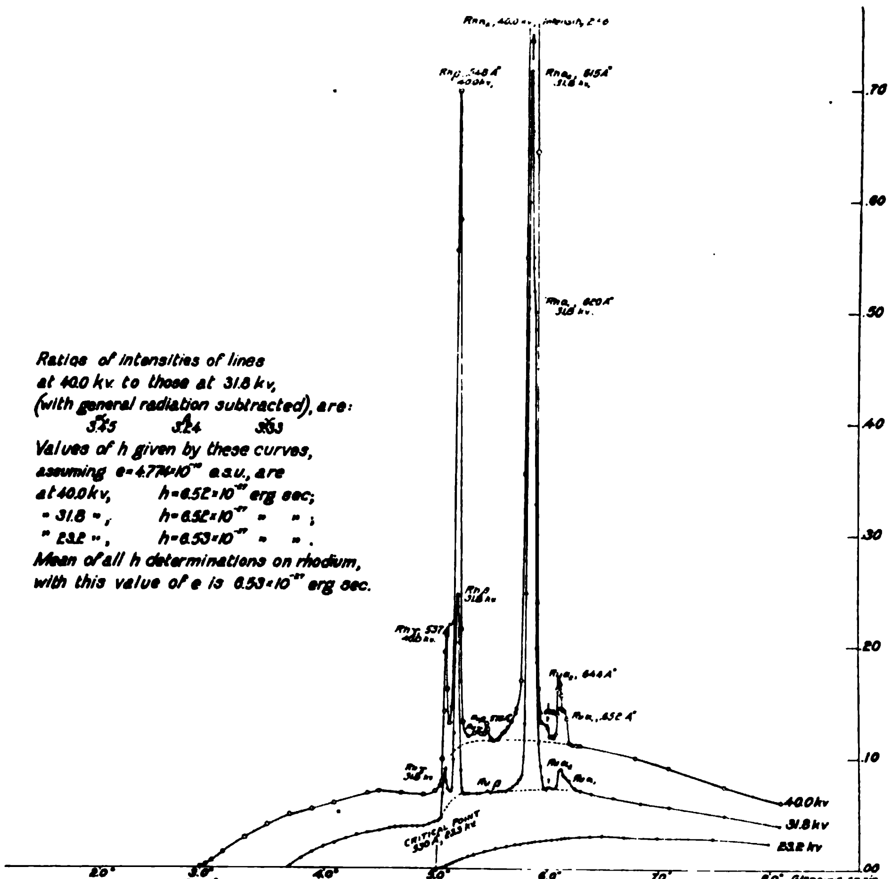

FIG. 1.—X-ray "spectra" of rhodium, or graphs of intensity against glancing angle at constant potentials.

on rhodium, and the latter from one by D. L. Webster and H. Clark[7] on platinum.

The most natural assumption, on the basis of the quantum theory, and the one that had usually been made, was that cathode rays of a uniform velocity would produce X-rays of a uniform frequency on their stoppage. The continuous nature of the general

radiation spectrum at a constant potential, as plotted by Duane and Hunt, was thus rather more suggestive of the pulse theory, although the pulse theory would not suggest a high frequency limit. As Webster[8] proved, the application of Fourier's integral to a pulse, or (what amounts to the same thing) the superposition of the secondary pulses reflected from the layers of atoms in the crystal, would show no high frequency limit for the spectrum obtainable

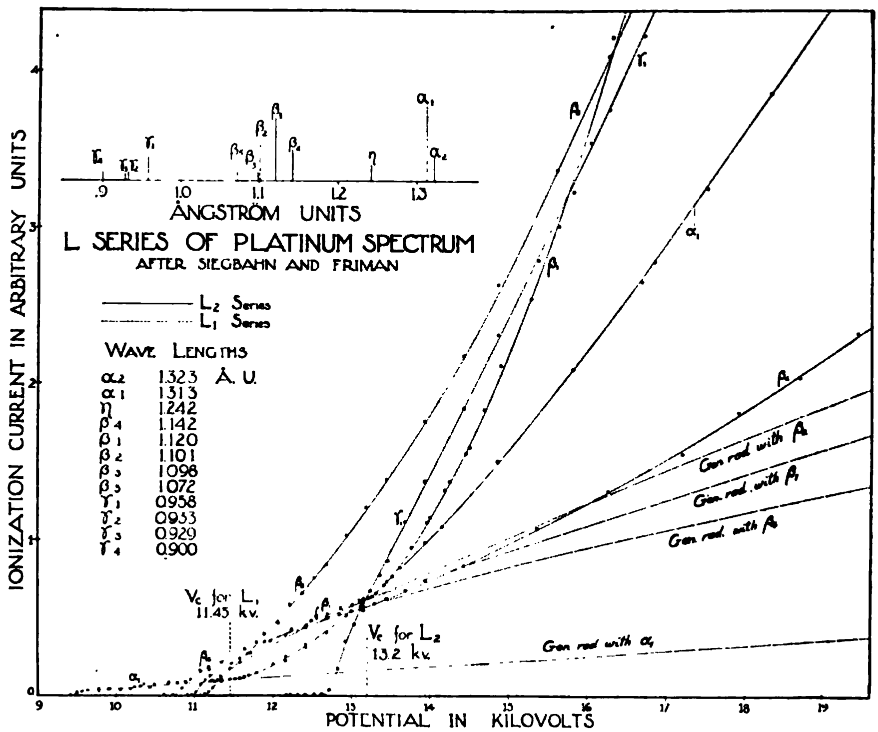

Fig. 2.—X-ray "isochromats" of platinum, or graphs of intensity against potential at constant frequencies.

from the pulse. This means that the pulse theory must be abandoned. The general radiation must therefore be emitted as a series of trains of periodic waves. A later analysis[9] dealt with the case of a target consisting of a single layer of atoms, where the cathode rays could not lose velocity by minor impacts before making such a direct hit as to cause X-radiation. In such a case it appeared that the discontinuity in the graph of intensity against either frequency or potential would not be in the first derivative of the intensity, but in the intensity itself. But at frequencies

below the quantum limit the intensity would still be finite. On the quantum hypothesis this indicates that an electron does not have to give up all its energy to radiation. This result was assumed independently by B. Davis[10] in a paper to be discussed below. (See Section on "Spectra at Different Potentials in a Single Direction.")

Duane and Hunt tested the quantum law for tungsten between 25 and 40 kilovolts. It was soon extended to several other cases. A. W. Hull[11] developed an ingenious combination of kenotrons, choke coils and condensers, for rectifying high tension current at a high frequency and smoothing it out into direct current almost as steady as a battery. With this he extended the law to molybdenum and up to 100 kv. Webster (see Fig. 1) tested it with Trowbridge's battery for a rhodium target in a Coolidge tube from 20 to 40 kv. and Webster and Clark (see Fig. 2) for platinum down to 9 kv.

Tests above 100 kv. involve great experimental difficulties, but a few have been made, notably those of Ledoux-Lebard and Dauvillier,[12] and of Dessauer and Bach. The former reached 140 kv. with a static machine, and tested the law to within 5 percent, the limits of error obtainable with current of this type. The later work of Dessauer and Bach,[13] with alternating current, tested it with about the same accuracy up to 170 kv. and even got one approximate measurement at 245. For voltages from 20 to 50 kv., Ulrey[14] tested it for chromium, nickel, molybdenum, palladium, tungsten and platinum, and Müller[15] from 17 to 28 kv. for copper and silver. Wagner,[16] using copper and platinum, extended the law downward from 10.5 kv. to 4. He used a battery and a gas-filled tube, and controlled the voltage by regulating the vacuum. The errors were very carefully estimated, and many measurements were made. The results obtained showed no change of h with voltage, and gave a mean value of 6.484×10^{-27} erg sec. Another very careful measurement was made by Blake and Duane[17] with a Coolidge tube giving the value 6.555. The difference between these results is rather a mystery. Is it possible that it can be explained by the higher initial velocity of the electrons knocked out of the cathode in the gas-filled tube, which might increase their energy above that given by the potential measurements? If so, it means that their initial energies must have corresponded to about 40 to 100 volts with tube potentials of 4,000 to 10,000, and must have

had a constant ratio (1 percent) to their energy on striking the target.

Another method of separation of X-rays, by filtration, has been used to overcome the difficulties of high voltage work, by Rutherford, Barnes and Richardson,[18] and by Dessauer.[19] The results are all abnormally small values of h. However, the filtration method in such cases has serious systematic errors, discussed in detail in Wagner's[20] excellent review of this subject, and all the other measurements indicate that the law probably holds exactly for an indefinite range both ways. The best value of h is probably very near that of Blake and Duane, 6.555×10^{-27} erg sec., which makes the product of the potential and the minimum wave-length equal to 12.345 kilovolt-Ångstroms. Ledoux-Lebard and Dauvillier[21] have proposed a correction of this value, on the basis of their new determination of the grating constant of calcite, 3.02825 ± 0.00225 Å, making $h = 6.556 \pm 0.015 \times 10^{-27}$ erg sec. This makes $V\lambda = 12.347$ kilovolt Ångstroms.

QUANTUM PHENOMENA IN CHARACTERISTIC RAYS

On the critical potentials of characteristic X-rays, the next work after that of Whiddington[2] and Beatty[3] was that of Webster,[6] from which Fig. 1 is taken. This dealt with the K series of rhodium and showed four laws: (1) on raising the potential on the tube, all the K series lines appear first at the same potential (called the critical potential); (2) the critical potential corresponds within limits of error, (1 percent), by the quantum relation, to the frequency of the absorption limit; (3) above this potential all the lines keep their intensity ratios constant; (4) the graph of intensity against potential for any line is concave upward, while the corresponding graph for the general radiation of a definite frequency is at first concave downward and later straight. Some spectra published by A. W. Hull and M. Rice,[22] at almost the same time as the above, indicate a similar critical potential for the K series of tungsten, and Wooten[23] extended the law to palladium and molybdenum. It probably holds for all the elements.

The absorption limit, that appears in the second of these laws, is the frequency where the absorptive power of the element is discontinuous, being almost eight times larger for slightly harder rays than for slightly softer ones. This discontinuity shows, in Fig. 1, indirectly, through its effect on the general radiation, because the rays escaped nearly tangentially from the surface of the target

where it had been roughened by the prolonged bombardment by the cathode rays. Now this greater absorption of the harder rays is accompanied by an ability of these rays to produce fluorescent characteristic rays, when they are absorbed, and softer rays do not have this ability. This, combined with the critical potential laws, would suggest that the process of production of characteristic rays from cathode rays is not direct, but that rays harder than the absorption limit are first formed (as general radiation) and then absorbed and turned into fluorescent characteristic rays. But Beatty in 1912 had shown that primary characteristic rays are much too strong to be explained in this way. This means that the appearance of the absorption limit in the critical potential law can be explained more probably by the hypothesis that the cathode rays themselves excite the same mechanism that would operate in fluorescence. On this hypothesis the four laws are all explained,[6] whatever this mechanism may be, and whether it is that of Bohr or something else.

In the L series, tests of the five strongest lines were made by Webster and Clark (see Fig. 2), who found two critical potentials, indicating two sub-series, called L_1 and L_2. There were also some lines of higher frequency than either of the points indicated by these critical potentials, showing that there must be at least one more sub-series, L_3. The lines belonging to either L_1 or L_2 obeyed the same laws as the K lines of rhodium, including the identity of each critical point with an absorption limit and the law of constant intensity ratios. Of course the intensity ratio of any two lines of different sub-series was far from constant. But if we compare such lines, not at equal potentials, but equally far above their respective critical potentials, their behavior is very similar. In all three series, K, L_1 and L_2, the intensities seemed to be roughly though not exactly proportional to the three halves power of the difference between the potential on the tube and the critical potential. Wooten's work on the K series, however, indicates a more exact agreement with the law derived theoretically by B. Davis, and discussed in his review of line intensities above.

Some of the L lines of medium strength were tested photographically by Webster,[24] and some fainter ones by Hoyt,[25] who used tungsten also, and who has kindly drawn the diagram shown in Fig. 3, which gives the results of this work up to date.

Evidently the theory of these critical potentials in the L series

must be much the same as in the K, and here again the process of direct production must be very similar to that of fluorescence, whatever that may be. The chief question is: Is that the process postulated in Bohr's theory, as developed by Kossel, Sommerfeld and others.[26] This theory has taken many forms, which are discussed in detail by W. Duane,[27] in his report on spectral series, published in this Series. The first important point here is what re-

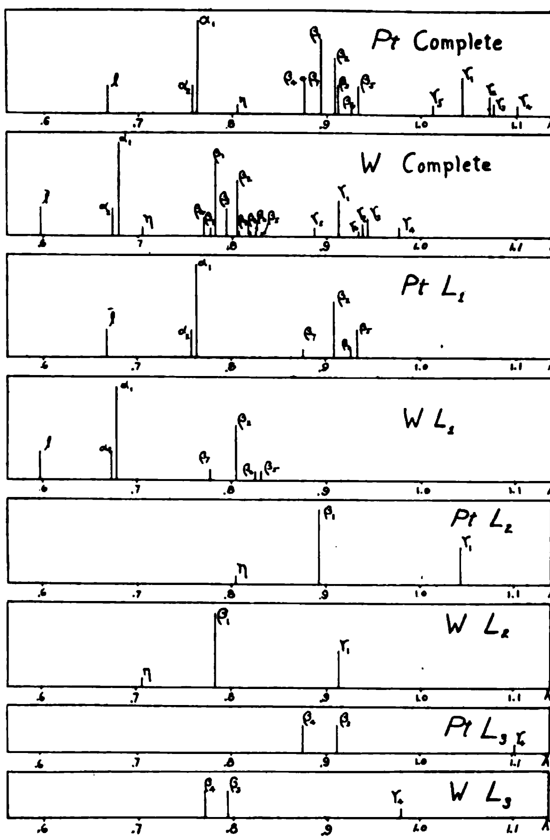

FIG 3

strictions on these forms are imposed by critical potential phenomena.

One of the chief restrictions, discussed in more detail in another paper,[28] is on the nature of the stable positions or orbits that electrons may occupy. In some theories all such positions, or at least all those generally concerned in X-ray processes, are filled when the atom is in its normal or undisturbed condition. In others,

some of them are normally empty. Of course the ones outside the boundary of the normal atom must normally be empty anyway. Now according to the Bohr theory, the process of X-ray absorption consists in lifting an electron from one of the inner rings beyond the boundary of the normal atom. The absorption limit is determined by the energy needed to just barely do this. To give fluorescent rays of the K series, the atom must absorb rays of a frequency whose quantum will at least lift an electron from the K ring, the innermost one, out of the atom. Its place is then taken by another electron, falling from a ring farther out. If it falls from one of the next two rings, which must be close together, we get one of the K lines. We can get the same line by knocking the original K electron out of the atom with a cathode ray. Hence this theory satisfies the requirement that the mechanisms working in fluorescent or direct characteristic rays must be the same. In some forms of the theory it has been assumed that the next two rings are normally empty. But in this case, why should we have to knock the K electron out of the atom? Why not simply to the first empty ring? That is apparently what we do in getting the "single line spectra" in light. Thus we find that these critical potential phenomena indicate that all stable positions used in X-ray processes (at least in the stronger lines) must be filled in the normal atom. This is the assumption made by Kossel and Sommerfeld. With regard to the weaker lines, especially those lying very near the absorption limits, recent work by Kossel,[29] Stenström,[30] Fricke,[31] and Duane and Patterson[23] indicates a probability that some of them, in series with long wave-lengths, involve the use of stable positions for electrons outside those occupied in the normal atom. If so, these lines must have properties intermediate between those typical of light and of X-rays.

Another restriction placed by this work on the Bohr-type theories is that each line must be associated with the absorption limit corresponding to its observed critical potential. Kossel,[33] in 1914, suggested that each line frequency is the difference of two absorption limit frequencies. Very accurate tests of this law for some of the stronger lines have recently been made by Duane and Shimizu,[34] Duane and Stenström[35] and Duane and Patterson.[36] If so, the critical potential of each line gives us at once the larger of these absorption frequencies. Knowing this, we ought to be able to predict definitely the smaller one for each line whose critical

potential we have determined. For the principal lines, where Kossel's law is known to hold, the larger absorption frequency involved is always the one indicated by the critical potential. But for some lines, such as L_l, L_η, and L_{β_4}, the smaller absorption frequencies one would predict have not yet been found. As these lines are all faint, the predicted limits, if they exist, are probably weak.

Another point where critical potentials have an important bearing on the absorption theory is in their evidence on the nature of the energy of an oscillator. The electron from one of these rings can be lifted out of the atom, apparently either by energy absorbed from radiation or by energy taken from a cathode ray, but not by any combination of both. If it is to be done by radiation, the frequency of the radiation must be such as to make one quantum at least as large as the total energy required, regardless of how many quanta may be in the neighborhood or how many cathode rays with slightly less energy may strike the atom. Similarly, if it is to be done by a cathode ray, the kinetic energy of this ray must be large enough to do the work alone, regardless of how many quanta of radiant energy or how many other cathode rays may be present. The atomic electron acts as if it were conscious, and knew where it must go and demanded a through ticket before it was willing to take chances to start. At best, this is strange behavior for such an object. But, assuming it to do this, we can at least say that its refusal to combine energy derived from two sources appears to indicate that there is almost no probability of the two sources acting at once. Now the action of a cathode ray is obviously quick, and two of them certainly will not often act together. But in the case of radiant energy, we might expect a much slower accumulation, simply because we naturally suppose that the waves are continuous. In fact, the phenomena of interference are very good experimental evidence that they are so, and that the energy—ability to do work, nothing more—is continuously distributed in each wave train. In many cases, where we use a narrow beam, or perhaps even a reflected one, we may be certain that the wave train from one radiating electron sends only a very minute fraction of a quantum of energy into the beam. But still every photoelectron has a whole quantum. This suggests some sort of an energy storage mechanism of a non-radiating sort, in the absorbing oscillator. But even this hypothesis has its de-

fects. It may be that, taking all the facts together, the simplest explanation will be found by postulating a statistical character for the law of conservation of energy, and replacing this law, for the individual oscillator, by a set of simple postulates suggested by the experimental facts. This question has been discussed elsewhere by Webster.[28]

SPECTRA AT DIFFERENT POTENTIALS IN A SINGLE DIRECTION

The problem of the distribution of energy among the different types of X-rays from the same tube is almost as old as the knowledge of the rays themselves. It figures prominently in such early work as Benoist's[37] studies of absorption, 1896 to 1901, and Trowbridge's[1] work with his battery, 1898 to 1900. It has always been most important in the application of X-rays. The literature on it is therefore very extensive. But from the point of view of the student of atomic structure and radiation, the essential facts found in the early studies are few. The chief ones are these: (*a*) the rays from a tube are harder (or of shorter wave-length) when the potential is higher; (*b*) the rays from a tube even at a constant potential are far from homogeneous. As in the subject of critical potentials, exact work was greatly facilitated by the invention of the Coolidge tube and the sources of constant potentials, and most of the data now available come from the papers quoted on that subject.

In that subject we have already seen the two methods of plotting, illustrated by Figs. 1 and 2 above. These graphs are of value not only for the study of the quantum law, but also for studying the intensity in the spectrum as a function of frequency and potential. They can also be taken for different directions relative to that of the cathode stream, to see if there is any of the asymmetry related to the Doppler effect, that one would predict from electromagnetic theory. For the present we shall confine our attention to experiments at a single direction.

At first sight it might seem that either set of graphs, "spectra" or "isochromats," would be equally useful in this study. The spectra, in fact, would appear to show intensity as a function of wave-length or frequency. But actually, they show only the ionizations observed at different frequencies. To find from them the intensity, or energy, four steps are needed. First, we must know the mechanical equivalent of the ionization unit, which varies with frequency, because of the changes in the absorptive power of the gas in the ionization chamber, and in the fraction of the absorbed

energy that goes into secondary cathode rays and thus into ionization. Second, we must know the transmission ratios of the window of the ionization chamber, the air and the glass of the X-ray tube, which also change with frequency. Third, we must know the reflection coefficient of the crystal, another function of the frequency. And fourth, we must know the fraction of the rays produced that get out of the target itself. This last point is well illustrated by the graphs in Fig. 1, in the discontinuity at the $K\gamma$ line, where the rhodium of the target has a discontinuity in its absorption coefficient, which accounts entirely for this effect.

At present, none of these four correction factors have been measured systematically and the results of such experiments as these are purely qualitative. They are, however, of considerable interest as showing not only the upper limit of frequency, at the quantum value, but also the existence of a maximum in the energy distribution as a function of wave-length, and the low intensity in the soft, long waves, at least in the rays that have come through the glass. As the voltage is raised this maximum shifts toward the shorter wave-lengths, thus explaining the well-known hardening of the beam as a whole. Quantitatively, this hardening of the beam as a whole is well illustrated by the filtration measurements at constant voltages made by Duane and Hunt[5] at 25 to 40 kv. and by C. D. Miller[38] at 2.5 to 10 kv., as well as by the spectra published in the papers quoted above.

The spectra also illustrate well the approximate similarity of the general radiation of different elements, first noted by Hull and Rice[22] and later by Lilienfeld,[39] and proved very clearly by Ulrey[14] in the spectra reproduced in Fig. 4.

A question has been raised by Lilienfeld[40] of a possible dependence of the mean hardness, and by inference of the position of the maximum in the spectrum, on the current density at the focal spot. This work has been severely criticised by Wagner,[20] and the result is contradicted by the more recent experiments of Behnken,[41] undertaken for the purpose of testing it.

Another point illustrated by the spectrum graphs, especially Ulrey's, is the dependence of the intensity on the material of the target. But in the absence of any dependence of the spectral distribution on the target material, the reader is referred for further data on this point to B. Davis' report on Total Radiation, above.

To correct for the unknown factors in these spectra is very diffi-

cult, but the problem has been attempted directly, by Dauvillier,[42] who has published approximate corrected spectra as shown in Fig. 5. These graphs show that the distortion of the spectra by these effects is indeed great.

The isochromats, on the other hand, are not distorted, because

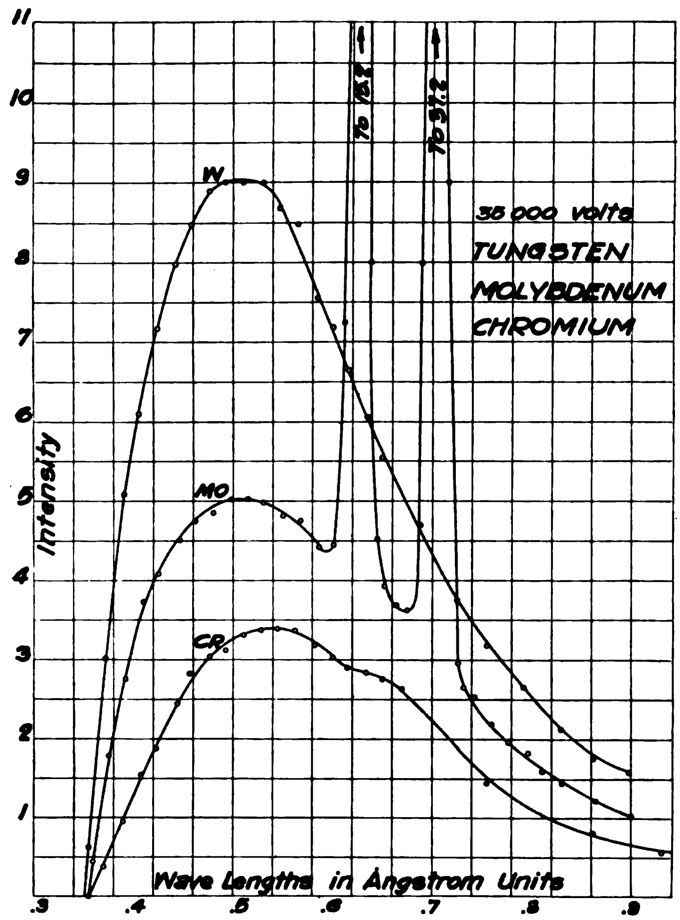

FIG. 4a.—X-ray spectra of different elements after Ulrey.

all the unknown factors are constant in each one. Only the relations between the different isochromats are doubtful. Their lack of distortion, however, gives them a distinct advantage, and for that reason they have been studied to some extent by Duane and Hunt,[5] Webster,[6] Webster and Clark,[7] and Wagner.[16,20]

The results are not yet very extensive, but they are all approxi-

mately like those of Fig. 2, and are given roughly by a formula proposed by Webster,[8]

$$I(V,\nu) = k(\nu)(V - H\nu) + H\nu p(\nu) e^{-q(\nu)\left(\frac{V}{H\nu} - 1\right)}$$

where $I(V,\nu)$ is the intensity considered as a function of the potential V and the frequency ν, $k(\nu)$, $p(\nu)$ and $q(\nu)$ are functions of V only, and H is the ratio of Planck's h to the charge of the electron.

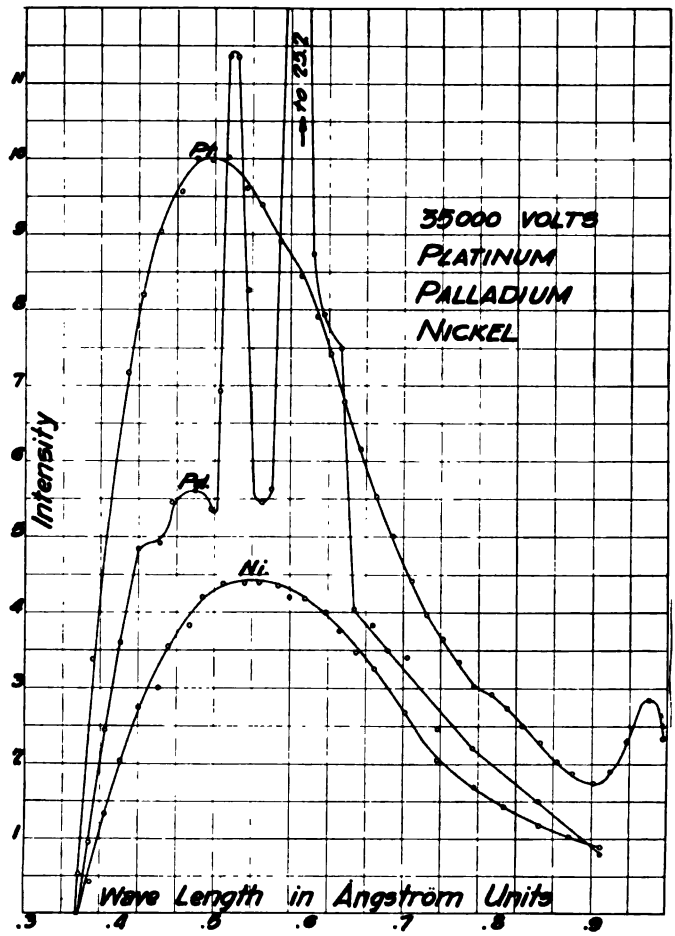

FIG. 4*b*.—X-ray spectra of different elements, after Ulrey.

This formula is only a first approximation. In it, p and q are pure numbers, and so are independent of the changes that occur in the energy equivalent of the ionization unit as we change the frequency. The data available at present indicate that p and q are nearly constant, at least for platinum. $k(\nu)$, on the other hand,

contains the ionization unit, and in fact is of the dimensions of ionization per unit of frequency interval and per unit of voltage. Thus a direct determination of it presents the same difficulties as correcting a "spectrum" graph.

Indirectly, however, we can get at $k(\nu)$ through the total radia-

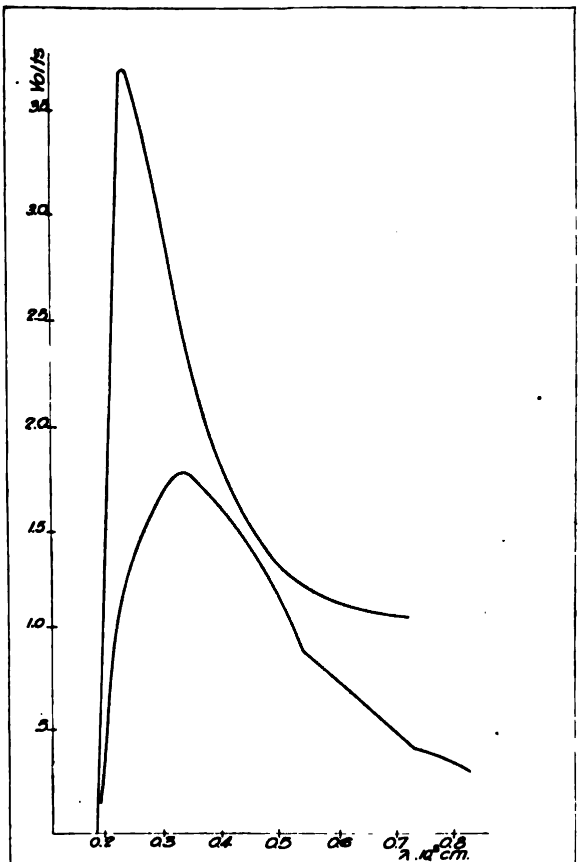

FIG. 5.—Spectrum of tungsten at 65.6 kilovolts, after Dauvillier. Lower curve, observed ionization; upper curve, spectrum corrected approximately for absorption factors and reflection coefficient.

tion, which is $\int_0^{V/H} I(V,\nu)d\nu$. If this is actually proportional to V^2 as found by Beatty[43] and others (see report by B. Davis on Total Radiation, above), and if p and q are really constant, then $k(\nu)$ must also be a constant.[44] But we must wait for more data which ought to be available very soon, before drawing a definite conclusion on this

point. Whatever the form of the functions p, q and k may be, we may be sure at least of the following facts:

(1) The isochromats or spectra all leave the axis of potential or frequency, respectively, at the value given by the quantum law and with a finite slope.

(2) The slope of an isochromat always decreases as we go up from the quantum potential, and the graph becomes practically straight with a slope considerably less than its initial value.

(3) The spectra, as plotted against wave-length, rather than frequency, always have a single maximum of intensity.

Let us now consider the problem of explaining these spectral distributions in terms of current theories. Using the Stokes pulse theory of X-rays the problem of the distribution of energy in the spectrum is merely one of representation of the pulse by a Fourier integral, in which the coefficient of the sine or cosine at a given frequency gives the amplitude of the vibration of that frequency, and its square gives the energy per unit frequency interval. Before the invention of the spectrometer, there was no way to test such an analysis, and find out whether any given form of pulse was experimentally possible. In 1915, such tests were made independently by Sommerfeld[45] and Webster.[46] The former considered the influence of a layer of matter containing electrons of low frequency. He proved that whether the electric vector in the pulse is initially all one way or subject to reversal, the passage of the pulse through the wall of the tube must give it such reversals as to make the algebraic mean of its electric vector equal to zero, and its spectrum will have an intensity approaching zero at low frequencies. The latter, considering the high frequency end of the spectrum, proved that the existence of a sharp high frequency limit in the spectrum violated the fundamental principle of the pulse theory and meant that the rays must be composed of trains of waves. A simple analysis shows that there must be at least a hundred waves in the train, and probably there are many more.

This makes it necessary to assume that most, if not all, of the general radiation comes from impacts of cathode rays on certain parts of the atoms such that a long series of vibrations will occur. Presumably they will continue until a quantum is radiated. The problem of energy distribution in the spectrum then becomes that of determining how often any particular frequency will occur in these series of vibrations. Here two courses are open: one to as-

sume that the atom has a mechanism that tends to vibrate in certain frequencies, and the other to assume that the cathode electron itself will vibrate with a frequency dependent, by the quantum law, on the energy it receives.

The former course is open to serious objections. First, there must be an infinite number of possible frequencies. An infinite number of absorption frequencies would be quite reasonable, with free or heavily damped electrons, but an infinite number of emission frequencies means a change of frequency with time, which, while not mathematically impossible, is not the most attractive postulate. A more serious objection is that the electrons with frequencies of X-ray order, that become evident in absorption, are probably not those concerned in the general emission spectrum, but only in the characteristic. For the general radiation has no discontinuity at the frequency where the absorption spectrum has one (unless absorption occurs in the path of the rays out of the target), but this frequency is the critical one for fluorescence and electronic excitation of characteristic rays. Thus, for the present, at least, we may dismiss the hypothesis of natural emission frequencies of the atoms producing the general radiation spectrum.

The other hypothesis, of frequencies controlled by the initial energy, also demands an infinite number of possible frequencies of vibration of either the striking electron or one that is struck. But this does not seem so improbable if the frequency used is determined by the quantum law, because this way of determining a frequency is so well in line with quantum phenomena in general.

In this case we have still two alternative hypotheses. One of them, suggested by Duane,[47] is that the electron vibrates with a frequency that increases as it penetrates into the atom. In this case the distance to which it can go and the maximum frequency it can attain, will depend on its initial energy. The problem then becomes one of finding how many vibrations it will make in getting through the region where its frequency lies in a given range, and fitting the energy thus emitted in each range of frequency to the experimental facts. The other alternative is that any one cathode electron vibrates with just one frequency, given by the quantum law, and radiates a whole quantum at that frequency. In this case the problem reduces to that of finding the probability of an electron's getting a given contribution of energy to be devoted

to radiation. This problem, like most of its kind, may be attacked from either end. We may assume some law of probability and deduce its consequences and test them, or we may get an empirical formula for the result and try to work back to the law of probability. The former of these ways has been tried by B. Davis[48] and H. Brillouin[49] and the latter by Webster.[50]

In Davis' theory the frequency emitted is assumed to depend on the energy due to the normal component of the cathode electron's velocity of impact on the atom, and the probability of its emitting at all is proportional to the same energy. Before it emits X-rays, the electron is assumed to lose energy in penetrating the target according to a continuous law, and it may cause emission at any atom it strikes. This theory gives a distribution of energy very much like some curves of ionization against wave-length at constant potentials, furnished by Duane and Hunt, and Hull, but the true curves of energy, rather than ionization, were not at hand, so no quantitative test could be made. The formula found by Davis for the intensity from a thick target is

$$\begin{aligned} w = kN\frac{R}{a}\nu_0\left(\frac{\nu}{\nu_0}\right)^2\Bigg\{ & \log\frac{\nu}{\nu_0} - \frac{1-a}{a}\left[1-\frac{\nu}{\nu_0}\right] \\ & + \frac{(1-a)(1-2a)}{4a^2}\left[1-\left(\frac{\nu}{\nu_0}\right)^2\right] \\ & - \frac{(1-a)(1-2a)(1-3a)}{18a^3}\left[1-\left(\frac{\nu}{\nu_0}\right)^3\right] \\ & + \frac{(1-a)(1-2a)(1-3a)(1-4a)}{96a^4}\left[1-\left(\frac{\nu}{\nu_0}\right)^4\right]\Bigg\}d\nu \end{aligned}$$

where w is the energy in the frequency interval $d\nu$, k and a are arbitrary constants, N is the number of cathode electrons striking the target, R their range in the target, and ν_0 the quantum frequency.

In Brillouin's theory the cathode rays after entering the target were assumed to acquire a distribution of velocities like those of gas molecules, but at a very high temperature. This leads to the formula

$$I(V,\nu)d\nu = \frac{2Hh^2\nu}{\sqrt{\pi k^3T^3}}(Ve-h\nu)^{1/2}\,e^{-\frac{1}{kT}(Ve-h\nu)}\,d\nu$$

where H is the number of cathode electrons per second, k the gas constant for one molecule, and T the fictitious temperature. This

formula was suggested but not checked against any data. Neither of these formulas seems to fit the isochromats well, but Davis' formula is much better than Brillouin's.

In Webster's theory the method is to start with a set of isochromats, because there the correction factors are constant in each graph. These are combined mathematically with Beatty's law of total intensity as outlined above, and then with the Thomson-Whiddington law of penetration of cathode rays in the target. The result is a law of intensity for a single layer of atoms struck by electrons of a single speed. This can be converted into a law of probability of radiating a quantum equal to any given fraction of the initial energy. If the potential is V the probability of radiation of a fraction between ϵ and $\epsilon + d\epsilon$ turns out to be

$$f(V, \epsilon)d\epsilon = \frac{bk}{2Nh} \frac{1 + pq\epsilon^{-q(1/\epsilon - 1)}}{V\epsilon} d\epsilon$$

where N is the number of atoms struck per unit length of path, and b is the constant of the Thomson-Whiddington law in the form

$$V^2 - V_x^2 = bx$$

k, p and q are the parameters of the original intensity graphs, that seem to be practically constant. This result is merely a first approximation based on very meagre data, as noted above, but with further data it ought to be possible, by the same method, to get an accurate probability law.

SPECTRA IN DIFFERENT DIRECTIONS AND POLARIZATION OF X-RAYS

Of all the factors producing differences in the X-ray emission in different directions from a tube, the one whose effects are most noticeable to the casual observer is absorption. This occurs, of course, most strongly in the target itself, and with a massive target it may almost entirely cut off the rays in one hemisphere. In the other hemisphere, its influence will naturally diminish as we go to directions farther removed from the plane of the surface of the target. Since the rays are produced very near the surface, we may ordinarily expect relatively little absorption except in directions fairly near this plane.

Further absorption, which may have considerable effect on distribution, occurs in the glass of the tube.

Now these effects, while of great importance in the practical use of X-rays, are of relatively little value to the student of atomic

structure. For him, the chief interest is in what distribution would occur around a target consisting of a single atom struck by cathode rays from a single direction. This problem must be attacked by means of targets of a visible size, and the absorption effects must be eliminated if possible. This being done, we may see what distribution occurs and what theory of radiation it satisfies best.

Historically the subject begins with work by Röntgen,[51] who found no inequalities but those due to absorption. Similar results were obtained by Walter[52] and Bassler[53] with platinum.

Nevertheless, a lack of symmetry could be expected from the very important discovery of polarization of X-rays made by Barkla[54] in 1904.

In the absence of noticeable refraction in X-rays, we cannot expect to detect polarization by double refraction, as in light, and the fact that ordinary polarizers and analyzers will not work here has indeed been tested by Chapman.[55] So we must use the method of polarization by reflection. But also we have no mirror reflection, such as we have in light, but only a volume reflection. This may look somewhat like mirror reflection in the case of a crystal, but it is more usually a diffuse scattering like the light of the sky. Light such as this is polarized, and scattered X-rays should be polarized in the same way and for the same reason. This is indicated not only by analogy, of course, but by the fundamental principles of the electromagnetic wave theory. Likewise the polarization of scattered X-rays, like that of light, should be greatest when the scattered beam is at right angles to the primary.

Reasoning in this way, Barkla[51] set up the apparatus shown in Fig. 6, taken from his paper of 1905. The rays from the tube fell on the square piece of cardboard or aluminum shown as R in Fig. 6, which scattered them in all directions, and the scattered rays could be measured by one electroscope on the same level as the cardboard, shown as A_1 in the figure, and another directly over the cardboard, shown there and called A_2. The primary beam was standardized by electroscope B. The rays to A_1 were thus parallel to the cathode rays when the tube was in the position shown here, while those to A_2 were perpendicular. The tube could be turned on an axis through the target, parallel to the primary beam, so as to reverse the relations of A_1 and A_2 to the cathode rays. Thus A_1 and A_2 ought to receive scattered

rays in proportion to the intensities of the two polarized components of the primary beam, provided the analogy with light was correct. The results showed a systematic change in the ratio of intensities in A_1 and A_2 whenever the tube was turned, showing that the primary beam was in fact partially polarized. In all cases the polarization was such as to indicate a stronger electric force parallel to the cathode rays than perpendicular to them, the difference in intensities being about 10 or 20 percent. In these experiments it was assumed that the rays scattered by R in the directions of A_1 and A_2 were completely polarized, as indicated by the electro-

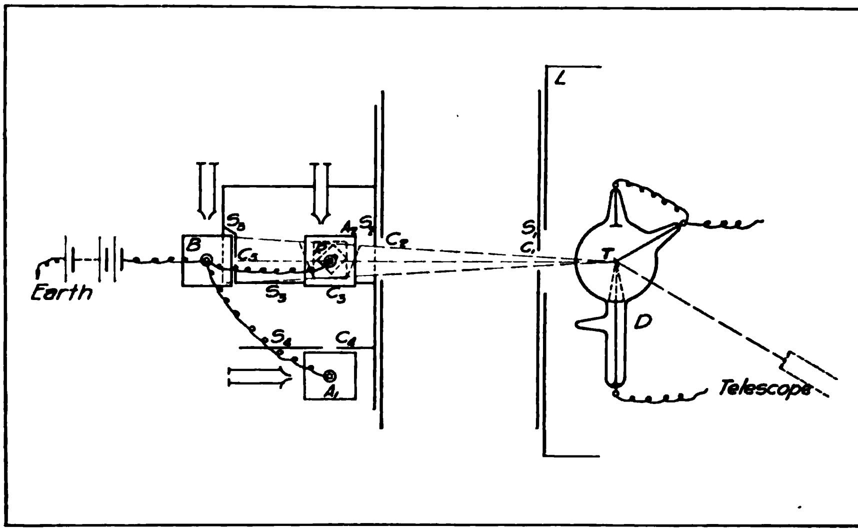

FIG. 6.—Barkla's apparatus for measuring polarization of primary X-rays. A_1, A_2 and B, electroscopes; R, rectangular paper radiator set at equal angles to the three directions, to A_1, A_2 and the target T. $S_1 \ldots S_5$ screens with apertures $C_1 \ldots C_5$. Tube can rotate about the line TC_5.

magnetic theory. Later work by Barkla,[56] where the scattered rays were analyzed by a second scatterer, confirmed this assumption for light elements such as carbon and aluminum. Elements such as iron, copper and tin failed entirely as polarizers, and so also as analyzers. Barkla explained this at the time as an effect of atomic forces on the electrons. Such forces also made themselves evident in the softening of the secondary rays, which, as he discovered later, for such elements as iron, were rays characteristic of the metal. These results were confirmed and extended by Haga,[57] Herweg,[58] Bassler,[53] and Vegard.[59]

This work of Barkla and the others on polarization is in com-

plete agreement with the electromagnetic theory of X-rays, coupled with the hypothesis that the accelerations of the radiating electrons are likely to have larger components in the line of the cathode rays than across it, but only about 5 or 10 per cent larger, on the average. If the accelerations were always exactly in this line, the theory would indicate not only complete polarization of the primary rays, but a zero intensity in directions along the line of the cathode rays, and a maximum at some direction generally not far from normal to this line. It would not be exactly normal to the cathode rays, however, because of the asymmetry, related to the Doppler effect, that would be indicated by the electromagnetic theory.

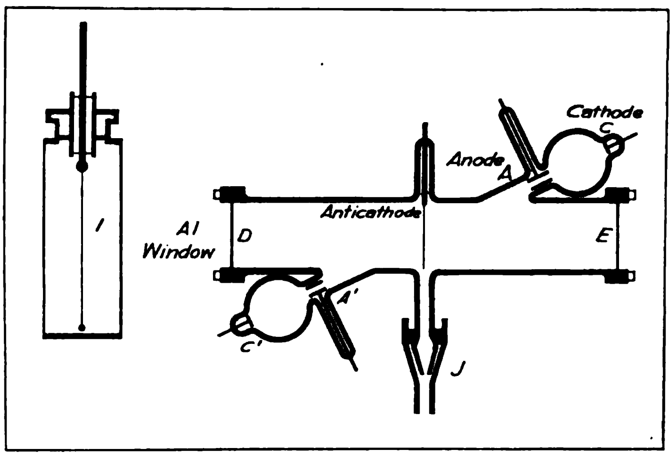

FIG. 7.—Kaye's apparatus for showing asymmetry of X-rays from a thin target, *C, C'*, cathodes; *A, A'*, hollow anodes; *D, E*, thin aluminum windows; *I*, ionization chamber; *J*, ground joint for rotating tube so as to use either end.

Turning to the corpuscular theories of radiation, such as Bragg's and Einstein's, one would expect a much greater asymmetry relative to the plane normal to the cathode rays, and a maximum of intensity in the line of the cathode rays themselves.

Definite evidence of a non-uniform distribution of primary X-rays, with this asymmetry the most prominent feature, was first found independently by Kaye[60] and Stark.[61] Kaye's apparatus, shown in Fig. 7, enabled him to measure the radiation emitted by a thin target of aluminum, copper, platinum or gold, each in leaf form. With this apparatus he got results that we may summarize as follows: (1) The forward radiation always exceeds the backward. The ratio of forward radiation to backward ranges from 1.30 to

3.20 for a single leaf of aluminum 10^{-5} cm. thick, and from 1.15 to 1.50 for a single leaf of gold of the same thickness. (2) This ratio increases, in general, with an increase of voltage. The voltages used may be estimated from his alternative spark lengths as about 5 to 50 kv. (3) In general, the forward beam is harder than the backward one, as predicted by the Doppler effect, but in the case of hard rays from aluminum, this result seems to be reversed.

Stark used a thick target of carbon, and measured his rays photographically, finding the very marked asymmetry shown in Fig. 8. At the same time he found the forward rays harder than the

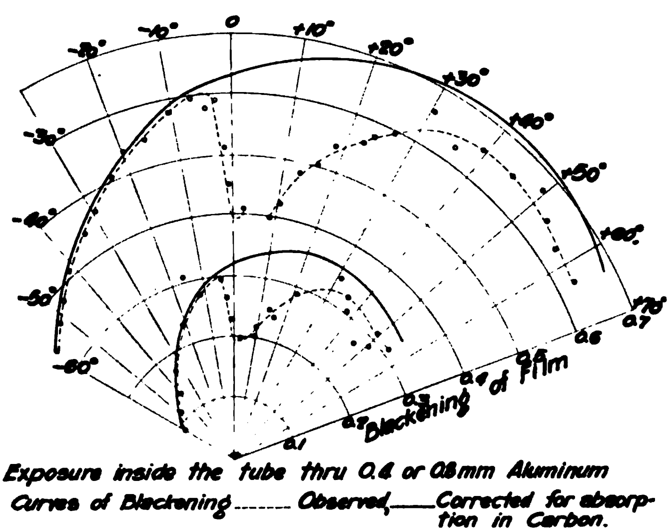

FIG. 8.—Intensities in different directions from a carbon target, after Stark. Direction of cathode rays is + 90 °.

backward ones. This he explained as evidence for Einstein's corpuscular theory of radiation, although the maximum of intensity, while forward of the perpendicular of the cathode rays, was not actually in the line of the cathode rays, as this theory would predict. However, that prediction was not an absolutely essential part of that theory. But Sommerfeld,[62] in the same year, analyzed the intensity effect related to the Doppler effect, mentioned above as a necessary consequence of electromagnetic theory. He showed that it would give just the sort of space distribution of intensity that Stark had found, and also that the Doppler effect itself would give his changes of hardness with direction, all on the basis of Stokes' theory of electromagnetic pulses.

Loebe,[63] in 1914, used a carbon target arranged quite differently from Stark's, and shaped as a half cylinder, so as to make the absorption uniform. He found results much like those of Kaye and Stark.

Ham[64] and Miller,[65] in the meantime, had investigated thick targets of lead and silver, respectively, and both had obtained a non-uniform distribution, with the maximum at right angles to the cathode rays, as one might expect from the simple theory of partial polarization without the Doppler effect. In each case the apparatus was constructed so that the absorption in the target and windows could be made exactly the same for any two directions to be compared.

Later, Friedrich,[66] using platinum, found effects more like those that Stark had found for carbon. But Kirschbaum,[67] with apparatus more like Stark's, used both platinum and carbon, and found the maximum intensities at points forward of the perpendicular for carbon, as Stark had found it, although in platinum it was almost on the perpendicular, showing no disagreement here from the results of Ham and Miller. However, the absorption in the target in this case makes it impossible to place the maximum intensity as exactly as Ham and Miller could.

The results of all this work on the total radiation in different directions are somewhat conflicting, but we may summarize them approximately as follows:

(1) With light elements or thin targets of heavy ones, the intensity has a maximum, in a direction making an acute angle with the cathode rays, as suggested by the hypothesis of partial polarization combined with a Doppler effect.

(2) With thick targets of heavy elements the maximum appears to be in a direction perpendicular to the cathode rays, as suggested by the simple theory of polarization without the Doppler effect.

(3) The excess of forward rays over backward seems in general to increase with any increase of speed of the cathode rays.

(4) The forward rays are in general harder, as one would predict from the Doppler effect.

This last point seems especially significant in view of our present knowledge of the existence of the definite upper limit of frequency given by the quantum law, which makes it necessary to abandon the pulse theory, that Sommerfeld[62] had used in explaining the difference of hardness. At the same time, the constancy of the

quantum, in X-ray measurements as well as elsewhere, makes it rather improbable that there would be any Doppler shift in this upper limit. Without such a shift of the limit, the hardest rays in a beam must be the least shifted by changes in direction. So we may expect the hardening and intensifying of the beam as a whole at small angles, if it is a true Doppler effect, to be primarily in the somewhat softer components.

Another significant point is the difference between Kaye's thin gold leaf targets, which gave an asymmetry of intensity, and Ham's thick platinum one which gave none. For there must be a great many slowly moving cathode rays in the interior of a thick target, that will produce soft X-rays and be unable to produce hard ones; whereas in the thin target the soft rays that are produced are all due to electrons that have energy enough to emit hard rays, but happen to strike the atoms in such a way as to emit soft ones. These fast electrons in a thin target, as we may prove by Webster's analysis of the isochromats, are actually much less productive of soft X-rays than the same number of slow electrons in the thick target. And, as noted above, soft rays produced by fast electrons are likely to be the only ones affected by the Doppler shift. If they are, this difference between thin and thick targets is explainable. Hence it may be used as further evidence on this point. But altogether, the evidence from these total radiation measurements is not perfectly conclusive, and it is most desirable to have actual spectrometric data.

A start on such data has indeed been made by Wagner,[68] who has published the two graphs shown in Fig. 9. These confirm exactly the conclusions drawn above.

This is particularly interesting in view of some consequences of these conclusions, noted by Webster[69] in a paper on the total radiation measurements. For let us assume that these effects are the true Doppler effect and the intensity change that accompanies it according to the electromagnetic theory. Then we must say that any cathode electron that emits its whole energy as a quantum must stop first, transforming its kinetic energy of translation into vibratory energy, and then it must vibrate about a fixed, or nearly fixed, center. But if the quantum to be emitted is only a fraction of its whole initial translatory energy, then it must transform that fraction into vibratory energy and keep the rest in the translatory form. Only by some such process can it give a true Doppler effect

to the train of waves emitted. This means it must vibrate about a center that moves continuously, and the motion must usually be at less than 90° from its initial direction. In other words, it must carry its whole vibrating mechanism with it, and not be dependent, for its restoring force in the vibration, on some fixed position in the atom in which it happens to be. This is an extraordinary idea, but for that matter, the very idea of a frequency determined only by the energy available is itself strongly suggestive of such a portable vibrating mechanism, even without this present evidence. In the present case, if the electron is to emit a train of a hundred waves, of a length, say, one Ångstrom each, it must take a time equal to $(100 \times 10^{-8}$ cm.$) \div (3 \times 10^{10}$ cm./sec.), or 3.3×10^{-17} seconds. If during this time it is going at a speed of, say, 10^{10} cm./sec.,

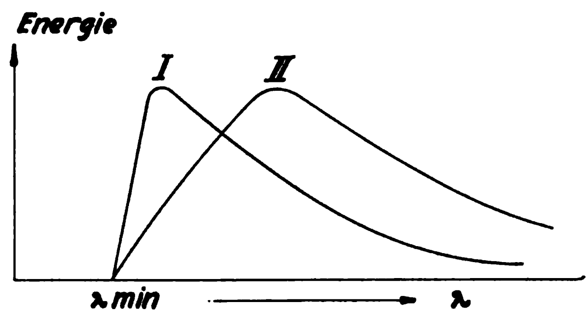

FIG. 9.—Spectra of rays in different directions with the same voltage, after Wagner. Curve I, forward rays; Curve II, backward rays.

it will go a distance of 3.3×10^{-7} cm., or 33 Ångstroms. This would carry it through about 10 atoms or so, in almost any solid, during the time it takes to emit one wave train.

The idea of an electron carrying its own mechanism of vibration with it is quite contrary to the postulate of a smooth spherical electron, that has usually been assumed in the electron theory. But so, for that matter, are the Bohr and Lewis-Langmuir atoms just as different from the indivisible, hard, spherical atoms assumed in the early days of the kinetic theory of gases. And this new idea of the electron is exactly in line with such an hypothesis as that of Parson's[70] magneton, especially as adapted to heat radiation by Webster[71] or to the scattering of gamma rays by A. H. Compton.[72]

But this does not mean that we know what an electron looks like, just yet, or even that this distribution of X-rays in space is explained really satisfactorily. For example, suppose an electron

strikes an atom, from a potential V, and causes radiation of a frequency ν, such that

$$h\nu = (1 - \eta)eV$$

where η is a fraction, not far from zero. Then its velocity after the impact is v where

$$\frac{1}{2}mv^2 = \eta eV.$$

The frequency emitted in the direction in which the electron is going ought then to be

$$\frac{(1 - \eta)eV}{\left(1 - \frac{v}{c}\right)h}.$$

In cases where η is nearly zero this may be written approximately

$$\frac{eV}{h}\left\{1 - \eta + \frac{1}{c}\sqrt{\frac{2}{m}eV\eta}\right\}.$$

Now as η approaches zero, this approaches $\frac{eV}{h}$, but from above, rather than below. In fact, its derivative is

$$\frac{eV}{h}\left\{-1 + \frac{1}{2}\sqrt{\frac{2eV}{mc^2\eta}}\right\}.$$

Now $\frac{mc^2}{2e}$ is of the dimensions of a potential, and equal to 253.7 kilovolts. So if $V = 63$ kv., for example, this derivative becomes

$$\frac{eV}{h}\left\{-1 + \frac{1}{4}\sqrt{\frac{1}{\eta}}\right\}.$$

This is zero for $\eta = {}^1/_{16}$ at which point the frequency emitted becomes

$$\frac{eV}{h}\left\{1 - \frac{1}{16} + \frac{1}{8}\right\}.$$

$$= \frac{eV}{h} \times 1.06.$$

This is so far above the observed limit $\frac{eV}{h}$ as to be definitely contrary to experimental facts.[73]

But with the effects observed, especially in Wagner's experiments, what hypothesis can we adopt? The facts seem to point to a Doppler effect at the lower frequencies, and there seems to be no other explanation of them on hand now. Is it possible that we are wrong in saying that *all* the energy of the cathode electron not going to radiation must remain as residual kinetic energy of

this electron alone? May not the particle it strikes get some of the energy? Or is there after all some totally different explanation of these effects? One point alone is certain: we need more facts.

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[73] Since this was written a paper has arrived, describing some experiments by G. Zecher (*Ann. der Phys.*, **63**, 1920 (28–55)), that seem to show an effect of just the sort indicated by this calculation. He used molybdenum at 80 kilovolts and found a Doppler effect of 11 per cent where the above theory would indicate about 8 per cent.

The evidence, however, is far from satisfactory, for Zecher used an induction coil and a set of gas-filled valve tubes. This made the potential very unsteady and the high frequency limit correspondingly indefinite—so indefinite, in fact, that it depended to a considerable extent on the time of exposure of his plates. And some of his other measurements indicated a difference in the high frequency limits at 90° from molybdenum and tungsten tubes running in parallel, which is contrary to the more reliable measurements made with direct currents by other observers, especially Hull and Rice, and Ulrey. But Zecher, himself, says this latter effect may be due to a difference in the tubes, rather than in the targets. In view of all these facts we have good ground for the belief that the observed difference in the high frequency limits in different directions may be due to absorption effects, and not to the Doppler effect that Zecher ascribes it to.

Even if this is a true Doppler effect, we certainly can not accept Zecher's explanation of it, as a confirmation of Sommerfeld's theory of 1909, which was based on the pulse theory. For, as noted above, this theory gives no explanation of the high frequency limit at all, and so it surely can not give a satisfactory explanation of any shift of such a limit. If the effect is real, it is more likely to be due to the causes discussed above.

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BULLETIN

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INTELLECTUAL AND EDUCATIONAL STATUS OF THE MEDICAL PROFESSION AS REPRESENTED IN THE UNITED STATES ARMY

BY MARGARET V. COBB AND ROBERT M. YERKES

CONTENTS

SUMMARY

I. Records

Records for approximately 2500 medical officers constitute the material for the statistical investigation herein reported.

II. Concerning Medical Officers

1. Intelligence.—The intelligence rating of medical officers is lower than that of other arms of the service with the exception of the Dental and Veterinary Corps. It is practically the same as that of the Quartermaster Corps.

When the results of intelligence examination are considered by tests instead of for the total examination, it appears that the scores differ widely for the several arms of the service. The psychograph (curve representing measurements for eight types of test which constitute army group-examination) for medical officers differs strikingly from that for artillery officers or that for engineers. This is still true of the medical group when it is broken into specialties. The psychographs of the several special medical groups have a very obvious family resemblance.

These differences in the relative degree of development or strength of intellectual functions for the professions of medicine and engineering may prove to have vocational or educational values, or both. The importance of further research is clearly indicated.

2. Factors affecting the intelligence status of medical officers.—Chief among the factors whose responsibility for the relatively low standing of medical officers has been suggested are: Age, habits of deliberateness and accuracy developed by professional training and experience, characteristics of the tests which render them easier for engineers than for medical officers, and method of military selection.

It has been shown by statistical analysis that age is significant. The military data indicate that median score of medical officers for army intelligence examination *a* diminishes from 277 points at 25 years to 258 at 30 years, 255 at 40 years and 223 at 50 years. Since about half of the group of medical officers in question are over 35 years of age, and 35% are above 40 years, and since also the average age of officers of other arms of the service is from 6 to 8 years less than that of medical officers, it is obvious that the relatively low intelligence rating of the medical group is partly

due to more advanced age. The form of the psychograph also changes with age.

Neither professional training and experience nor the characteristics of the tests importantly influence, so far as analysis indicates, the intellectual rating of the medical group.

Method of selection, on the other hand, appears to be responsible to at least as great an extent as is age for the unsatisfactory intelligence of medical officers. Whereas, for most other arms of the service candidates for commission were sent to officers' training schools and there subjected to rigorous training and systematic examinations which tended to eliminate the intellectually incompetent, appointments to the Medical Corps, because of the imperative need for large numbers of medical officers, were made directly on the basis of age, certification by the American Medical Association, experience (and sometimes professional examination), prior to enrollment in the medical officers' training camp. This difference in procedure undoubtedly worked to the disadvantage of the Medical Department, so far as the intelligence of its officers is concerned. In the Medical Corps experience and professional reputation counted heavily. In the other arms of the service military educability and adaptability under the eye of instructors with whom rested the power of recommendation counted most of all.

Given identical age groups and similar methods of military selection, it seems probable that the intellectual status of the Medical Corps would differ little from that of the Engineers or Artillery. The psychographs for these groups might, however, differ extremely, thus indicating either primary differences in intellectual constitution or differences induced by professional training and experience.

3. Education.—The typical medical officer is a high school graduate with about four years' professional training. He has devoted more of his life to schooling than has the officer of any other arm of the service. His median length of schooling is 15.8 years, whereas that of the Engineer is 15.3 and of the Quartermaster 12.4.

4. Experience.—In general the medical officer is more experienced than any other type of officer. The medical group studied reported 11.07 years of experience. This fact gives point to the statement made above that experience was an important consideration in the appointment of medical as contrasted with other officers.

5. Geographical relations.—When classified by section of the country from which they were graduated or certified, or in which they practiced, these medical officers exhibit substantial differences in intelligence, earnings and experience. Generally speaking, the northeast, the central and the northwest sections of the country show superiority over the south and south central sections.

Intelligence and earnings vary also with the population of the community in which the medical officer (as civilian, of course) practices. The order of increasing values for intelligence is rural, urban, metropolitan; that for earnings, rural, metropolitan, urban.

6. Earnings.—The annual earnings reported by these medical men vary signally with geographical location, population of community, professional specialty, experience and medical school. The correlation between intelligence and earnings is extremely low.

7. Military relations.—Medical officers of the Regular Army Medical Corps and of the National Guard achieved somewhat higher intelligence ratings than those of the Medical Reserve Corps.

Intelligence is highly correlated with rank in the Medical Corps. This indicates, to the credit of the Medical Department, that superior intelligence tends to dominate in the rank of major and above. Promotion also depends to a significant degree on intellectual capacity, as is indicated by the intelligence ratings of promoted versus non-promoted officers.

The data of this report justify the statement that the Medical Corps obtained the services of the ablest as well as the weakest men of the profession. Had the latter been eliminated by a rigorous procedure of intelligence tests, combined with professional examination, the status of the group would undoubtedly have compared favorably with that of any other professional group in the army.

8. Membership in societies.—The typical medical officer of this group claims membership in two or three medical societies, one of which is usually the American Medical Association.

III. Concerning Medical Schools

1. Classification.—More than 130 medical schools are represented by the 2507 medical officers statistically considered. The numbers from these schools vary from 1 to 118. Grouping of the schools for statistical purposes was necessitated by the small number of individuals from most institutions. Five classifications have been made: By geographical location, by size (number of stu-

dents registered in 1916–1917), by entrance requirements, by American Medical Association rating, and by medical sect.

2. *Geographical classification.*—The intelligence ratings and earnings of graduates from schools in different sections of the country correspond in general to the same information for the medical men resident in those sections.

3. *Classification by size.*—The schools represented in the medical group were separated according to size into 8 divisions ranging from those having less than 50 students in 1916–1917 to those having 400 or more. The men graduated from the larger institutions make, on the whole, a somewhat higher intelligence rating on examination alpha than those graduated from the smaller. Earnings, on the other hand, are not closely correlated with the size of the school.

4. *Classification by entrance requirements.*—This classification was made on the basis of requirements enforced in 1916–1917. The intelligence of the medical officer is highly correlated with the standard of entrance requirements of the school from which he was graduated. The median score, in army examination alpha, of graduates from schools requiring but one year of college work in addition to high school graduation is 118.7, whereas that of graduates from schools requiring more than 3 years of college work is 154.2, a difference of 35.5 points. The earnings reported by men from schools with high entrance requirements are also strikingly larger than those from schools with low entrance requirements.

5. *Classification according to rating of the American Medical Association.*—The difference in median alpha scores, between graduates of schools rated "A" by the American Medical Association and those rated "C," is 17.3 points, which, though significant, is less than half as great as the difference between schools of the highest and lowest entrance requirements. The difference in earnings between classes "A" and "C" is comparatively small.

6. *Classification by medical sect.*—In both intelligence scores and earnings the graduates from homeopathic schools stand as much above the eclectic schools as the class "A" schools are above the class "C" schools. Graduates from "regular" schools fall approximately half way between the other two.

7. *Comparison of schools.*—A detailed comparison (table 43) of the graduates of the 18 schools which were represented in the medical group by more than 35 students each shows that the

median intelligence rating is A for seven schools. Median earnings of $5000 or over are reported by the graduates of eight schools. The southern schools on the whole show lower scores, less schooling, lower earnings and fewer promotions than the northern.

HISTORICAL STATEMENT

The psychological examination of officers in the United States Army very promptly indicated that the intellectual status of medical officers was less satisfactory than that of officers of several other arms of the military service. Colonel Henry A. Shaw, of the Regular Army Medical Corps, invited the attention of the Surgeon General to this fact in a report, submitted November 16, 1917, which he based upon observation of the psychological service and data of examination at Camp Lee, Virginia.[1]

Table 1, quoted from Colonel Shaw's report, indicates the remarkable differences in frequency of A and also of A and B grades, that is, very superior and superior intelligence, for officers of different arms of the service. Thus, for medical officers there are 27% of A grades; for engineers, 66%. Colonel Shaw remarks:

> Comment on these figures is unnecessary. They speak for themselves. The only question is whether or not they represent a true state of affairs. With reference to the comparative efficiency of the officers of the various arms of the service I am not in a position to judge. I am of the opinion, however, that the order of mentality as shown by the psychological scores is fairly close to the truth. It is reasonable to believe that the engineers have succeeded in attaching to their corps a larger number of technically trained young men than any other branch of the service. It is also probable that the officers' training camps have drawn into the commissioned grades a larger number of college-trained men than either the Quartermaster or the Medical Corps.

The psychological findings, Colonel Shaw's comment thereupon and his recommendations to the Surgeon General aroused the critical interest of the medical profession. It was variously suggested that differences in age, education, basis of selection, or applicability of the intelligence tests might be responsible for the relatively unsatisfactory showing of medical officers. Because of the general interest in these results and the discussion which they provoked, their later correction or confirmation became important.

[1] On November 19 Colonel Shaw transmitted to the Surgeon General a special report on the psychological ratings of medical officers. This report is quoted entire in "Psychological Examining in the United States Army" (official report), *Memoirs of the National Academy of Sciences*, 15 (22–23). (In press.)

It is proposed to present in this report results which were secured during 1917 and 1918 in a large number of army camps and which undoubtedly represent fairly the officer personnel of the army with respect alike to its medical component and the other arms of the service. Colonel Shaw's report, by contrast, was based upon preliminary results in only one camp.

TABLE 1

Distribution of intelligence (Letter grades A to D) in different arms of the military service[1]

Letter grades	All officers Percent	Medical Corps Percent	Engineers Percent	Artillery Percent	Infantry Percent	Quarter-master Corps Percent
A.........	44	27	66	57	44	40
B.........	32	33	29	31	38	32
C.........	24	40	5	12	18	28
D.........	0	0	0	0	0	0

Although approximately 43,000 officers were given psychological examination, the Division of Psychology of the Surgeon General's Office, because of limited resources, was able to use only about 15,000 of these records for statistical purposes. Of the 15,000 about 3000 were the records of medical officers. The intelligence measurements available for these men were studied by the aid of the Hollerith method and a very brief and general statement on the status of medical officers was prepared for the official report to the Surgeon General concerning psychological examining in the army (see tables 2 and 3 herewith). While this work was in progress Dr. Robert H. Halsey of New York suggested to the Chief of the Division of Psychology the importance of arranging for a careful and thorough-going study of the data on medical officers which were available in army records. Following this suggestion, the Division of Psychology secured the coöperation of the Division of Medicine and Related Sciences of the National Research Council, which supplied adequate funds for the work.

It was promptly arranged that Miss Margaret V. Cobb, under the supervision of the Chief of the Division of Psychology of the Sur-

[1] The letter grades are defined on page 467. The data of this table were obtained with army group-examination *a*, which was later revised and designated examination alpha, given to 1,166 officers, Camp Lee, Va. Percentages are taken from Table 1, p. 22, of the official report cited above.[2]

geon General's Office, should conduct this special inquiry for the National Research Council and the Surgeon General of the Army.

METHODS AND MATERIALS

The statistical study of medical officers reported below was conducted in accordance with the following general plan and with the data which are hereafter enumerated. From the 3000 records of medical officers which were immediately available for use in the office of the Surgeon General, selection was made on the basis of completeness of information. This selectional process reduced the group to about 2500. There is every reason to believe that this group fairly represents the medical profession as it existed in the United States Army during the war, and it is probable that it also fairly represents the medical profession of the United States of America.

The following important items of information concerning each

Sample Record

Name..................	NG RA (RC) NA USA **Rank** Lt. Col.	
Residence...............	**Pop. of community** 475,367	**Age** 44
High sch. 0 1 (2) 3 4	**Col.** 0 1 2 (3) 4 5	**Med. col.** 0 1 2 3 (4) 5 6
Jefferson Medical College, Philadelphia, Pa.		**Yr. grad.** 1899
Years of education: 17	**Pre-med.** 13	**Med.** 4
Training:	**Hospital**	**Clinical**

Alpha		Scott ratings					
Test	Score	1st	2nd	3rd	4th	5th	
1	8	12	10	9	..	..	**Certification,** Indiana '01
2	8	15	12	12	..	..	**Years experience,** 19
3	12	15	12	12	..	..	**Societies,** Los Angeles Co. Med. Soc.; California State Med. Soc.; Clin. and Pathol. Med. Soc.; Am. Acad. Med. Sciences; Am. Med. Ass.
4	34	15	12	12	..	..	**Specialty,** Internal medicine
5	18	40	32	30	..	..	**Assignment,** Permanent Staff
6	12	..	..	..	..	..	**Promotions,** Maj. to Lt.-Col.
7	13	..	..	..	..	..	**Professional examination,** Qualified
8	35	..	..	..	..	..	**Annual earnings,** $42,500.00
Total	140	97	78	75			**Station,** Camp Lewis
Rating	A						

individual were available in the files of the Surgeon General's office: name, residence, age, rank, promotions and military assignment, pre-medical education, medical education, medical school, hospital experience, intelligence grade, Scott rating, place of certification, years of medical experience, membership in medical societies, specialty and annual earnings.

These several items were assembled for statistical purposes on a single record card, such as appears in the accompanying sample records of four medical officers. These samples are presented to indicate the nature and arrangement of the information which was available and the contrast among medical officers.

Sample Record

Name.................. NG RA (RC) NA USA **Rank** Captain
Residence............... **Pop. of community** 745,988 **Age** 39
High sch. 0 1 2 (3) 4 **Col.** 0 1 2 3 4 5 **Med. col.** 0 1 2 3 (4) 5 6
Baltimore Medical College, Baltimore, Md. **Yr. grad.** 1906
Years of education: 15 **Pre-med.** 11 **Med.** 4
Training: **Hospital,** Yes **Clinical**

Alpha		Scott ratings					
Test	Score	1st	2nd	3rd	4th	5th	
1	10	12	12	..	..	..	**Certification,** Indiana, '06; Michigan, '07; **Years experience,** 12
2	12	12	12	..	..	..	**Societies,** St. Louis Med. Soc.; Acad. of O., L. and O.; Ind. State Med. Soc.; Mo. State Med. Soc.
3	9	9	12	..	..	..	
4	23	12	12	..	..	..	
5	12	24	30	..	..	..	
6	7	..	..	..	..	..	**Specialty,** Ear, nose and throat
7	24	..	..	..	..	..	**Assignment,** Eye, ear, nose and throat
8	30	..	..	..	..	..	
Total	127	69	78				**Promotions,** 0
Rating	B						**Professional examination,** Qualified
							Annual earnings, $4000.00
							Station, Camp Sherman

Of the items of information available those of primary importance in this study are: Intelligence, pre-medical education, medical education, medical school attended, experience, geographical location, population of community and earnings.

Sample Record

Name.................... NG RA (RC) NA USA **Rank** Lieutenant
Residence.............. **Pop. of community** 200 **Age** 42
High sch. 0 1 2 3 (4) **Col.** 0 1 2 3 (4) 5 **Med. col.** 0 1 2 3 (4) 5 6
Marquette University, Milwaukee, Wisconsin **Yr. grad.** 1910
Years of education: 20 **Pre-med.** 16 **Med.** 4
Training: **Hospital,** None **Clinical**

Alpha		Scott ratings					
Test	Score	1st	2nd	3rd	4th	5th	
1	5	6	9	8	7	9	**Certification,** Wisconsin, '10; Minnesota, '11
2	6	6	6	10	10	7	**Years experience,** 8
3	3	6	6	9	7	10	**Societies,** Red River Valley Med. Ass.; Minn. Med. Ass.; A. M. A.
4	10	6	9	8	10	6	**Specialty,** General Practice
5	1	24	16	22	24	23	
6	7	..	..	..	..	..	**Assignment,** Field Service
7	5	..	..	..	..	..	
8	11	..	..	..	..	..	**Promotions,** 0
Total	48	48	46	57	58	55	**Professional examination,** Barely satisfactory
Rating	C						**Annual earnings,** $700 (country practice)
							Station, Camp Lewis

An attempt will be made to exhibit the principal facts with respect to these various data concerning medical officers, the relations of these facts among themselves, and their significance for medical education and professional activity.

For the benefit of readers who are not familiar with the army method of psychological examining or the Scott rating scale, a brief explanation of each will be given at this point.

Group Examination Alpha

The psychological examination given to the officers whose ratings are used in this report is known as examination alpha.[1] It was used for the examination of soldiers by groups and consisted of eight separate tests, the time limit on which was so short that

[1] Complete description of methods of psychological examining used in the army may be found in "Army Mental Tests," Henry Holt and Company, New York, 1920; or in "Psychological Examining in the United States Army" *Memoirs of the National Academy of Sciences*, 15. (In press).

Sample Record

Name.................. NG RA (RC) NA USA **Rank** Captain
Residence.............. **Pop. of community** 5,468 **Age** 51
High sch. (0) 1 2 3 4 **Col.** (0) 1 2 3 4 5 **Med. Col.** 0 1 2 (3) 4 5 6
Kentucky School of Medicine, Louisville, Ky. **Yr. grad.** 1892
Years of education: **Pre-med.** **Med.** 3
Training: **Hospital** **Clinical**

Alpha		Scott ratings					
Test	Score	1st	2nd	3rd	4th	5th	
1	1	7	..	..	..	..	**Certification,** Ohio, '96
2	3	9	..	..	..	..	**Years experience,** 26
3	4	7	..	..	..	..	**Societies,** Jackson Co. Med. Soc.; Ohio State Med. Soc.
4	1	10	..	..	..	..	**Specialty,** X-ray, rheumatism, skin and blood diseases
5	1	15	..	..	..	..	**Assignment,** General Service
6	1	..	..	..	..	..	**Promotions,** 0
7	3	..	..	..	..	..	**Professional examination,** Qualified
8	5	..	..	..	..	..	**Annual earnings,** $900
Total	19	45					**Station,** Camp Greenleaf
Rating	D						

very few men could finish a given test. These several tests are describable by title as: Test 1, oral directions; test 2, arithmetic; test 3, practical judgment; test 4, opposites; test 5, disarranged sentences; test 6, number series completion; test 7, analogies; test 8, information. The examination required approximately fifty minutes. Papers were scored by the use of stencil-keys and the ratings were wholly objective. Although a numerical score was assigned to each man, for convenience of classification letter grades were also used in the army. The maximum score for the examination was 212 points and the letter grades used were as follows:

Intelligence grade	Meaning of grade	Range of score
A	Very superior intelligence	135–212 points
B	Superior intelligence	105–134 points
C+	High average intelligence	75–104 points
C	Average intelligence	45–74 points
C—	Low average intelligence	25–44 points
D	Inferior intelligence	15–24 points
D—	Very inferior intelligence	0–14 points

The Scott Rating Scale

The Scott rating scale[1] is a plan for the rating of officers by their superiors. Each individual is rated, in accordance with definite directions, on five groups of characteristics, namely: physical qualities, intelligence, leadership, personal qualities, general value to the service. The total number of points allowed for these five categories is 100, distributed as follows: 15 for each of the first four groups, 40 for the last.

Comparison of the Scott ratings of medical officers, made during the assembling of the data for this report, indicated surprising inconsistencies between the ratings given to the same officer at different times. It was at first proposed to obtain an exact expression of this seeming unreliability of the ratings in order that safe decision might be reached concerning the value of these data. But before statistical analysis could be made an unpublished report on the Scott ratings prepared by H. O. Rugg became available.[2] The statements of this report clearly indicated the undesirability of using the Scott ratings for comparison with the other data of this report. They appear on the sample record cards on pages 464–467, but no statistical use has been made of them.

The results of professional medical examination in the army were not available when this work was undertaken. They would undoubtedly have value and it is regretted that they could not be included with the other materials.

DATA CONCERNING MEDICAL OFFICERS

Analysis of the records of approximately 2500 medical officers supplies data for the following general description of the group

[1] Detailed description of the Scott rating system and its results in the army is available in "The Personnel System of the United States Army: Vol. I, History of the Personnel System; Vol. II, The Personnel Manual." War Department, Washington, 1919.

[2] Dr. Rugg finds, after checking the ratings as to agreement of successive ratings with one another and as to their agreement with psychological and other objective tests and other measures supported by accepted practice in the army, that "prior to October the validity of ratings which were recorded on officers' qualification cards may be seriously called in question," and later adds "the probability is not great that the October ratings which were studied are much more valid as measures of officers' ability in the army than were the July ratings." There were average differences between the first and second quarterly ratings, even when made by the same officer, of nine points on the scale (this is at least one-sixth of the usual range of the scale); when different officers made the ratings average differences were from nine to seventeen points. Even among especially careful ratings he finds the variability of judgment to be "so very great that the probability is very remote that a single rating located an officer in his proper group" (*i. e.*, proper fifth of the range of the scale). This was true also under standardized experimental conditions.

in terms of age, geographical origin, intelligence, education, professional experience, earnings, membership in medical societies and specialty.

The average medical officer of the group studied is a man 37 years of age, practicing somewhere in the United States in a town of approximately 12,000 population, whose intelligence as measured by army examination alpha is of grade B (alpha score 129 points). Following a high school education, he was graduated, after a five-year medical course, in 1907, from a college of 250 students. His annual earnings are reported as $4318.00. He is a member of two or three medical societies, the chances being even that one of these is the American Medical Association. There is also an even chance that he claims no specialty other than his general or surgical practice and that he was not promoted during his service in the army.

Intelligence of Medical Officers

Quantitative differences.—It would have surprised no one had the medical officers of the United States Army, during the war, ranked with the best of the arms of the service in intellectual ability; their failure to make a relatively good showing naturally evoked comment both within and without the profession and aroused speculation as to the reasons. The principal facts concerning the intellectual status of military officers are summarily presented in tables 2, 3 and 4 of this report. For more detailed information

TABLE 2

Percentage distribution of psychological grades for examination alpha of officers of different arms of the service.[1]

Arm	D	C—	C+	C	B	A	A and B	No. of cases
Engineers	...	...	0.3	2.4	13.8	83.0	96.8	1026
F. Artillery	...	...	1.1	5.9	23.0	70.0	93.0	1523
Sanitary Corps	...	...	2.0	8.2	31.6	58.2	89.8	98
Field Sig. Bn	0.3	0.3	2.2	9.0	24.1	64.1	88.2	357
Mach. Gun Bn	...	0.4	2.2	10.7	30.1	56.5	86.6	495
Infantry	...	0.3	3.0	12.2	28.5	56.0	84.5	6942
Quartermaster	...	0.9	5.2	15.7	30.2	48.0	78.2	756
Medical	...	0.6	5.2	17.6	32.9	43.6	76.5	3180
Dental	0.2	0.2	4.0	20.4	41.1	34.1	75.2	423
Veterinary	...	0.4	7.9	30.8	38.7	22.1	60.8	98

[1] Official report, table 397, p. 852.

and discussion reference should be made to the official report on psychological examining cited on page 462.

The proportions of the several letter grades for the chief army corps or arms of the service appear in table 2. They are arranged in order of diminishing number of A and B grades. The remarkable difference in the frequency of superior and very superior intelligence in the Medical Corps as compared with the Engineer Corps demands explanation. Over twice as many of the officers of the latter

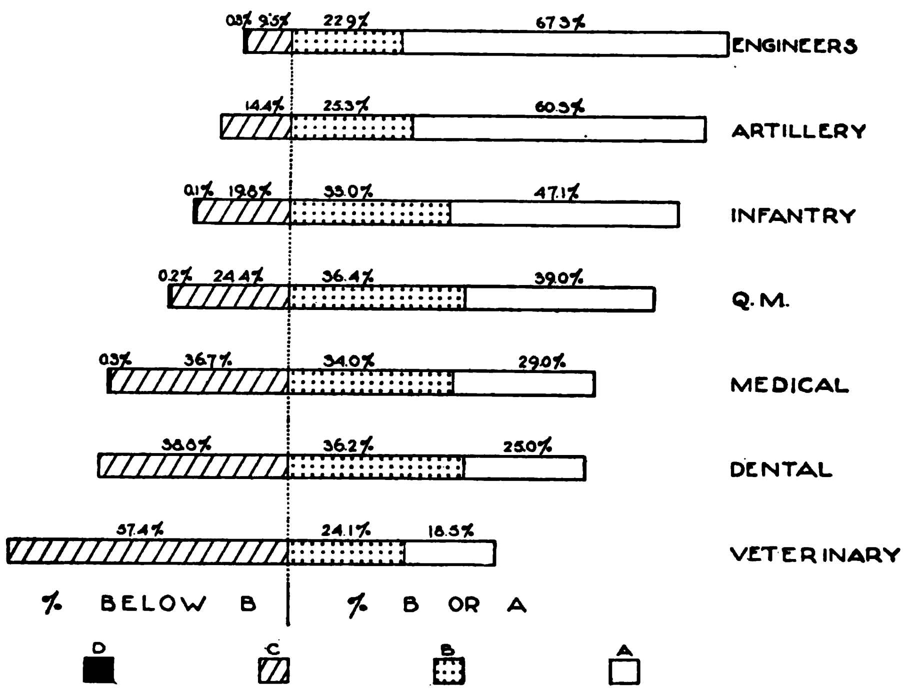

Fig. 1. Comparison of officers by arms, showing percentages in each letter grade. Combined data from Camps Devens, Dix, Lee and Taylor. Engineers, 336; Artillery, 680; Infantry, 2,050; Quartermaster Corps, 470; Medical, 639; Dental, 116; Veterinary, 54. This is fig. 22, p. 518, Official report on psychological examining.

group as of the former achieved the highest letter rating, A. Figure 1 presents graphically these data summarized for purposes of rough comparison.

Table 3 renders available to anyone who may wish to study the data the distribution of scores in psychological examination alpha for more than 15,000 army officers. The median scores for these several distributions are of special interest and importance in this report. Except that Field Artillery and Sanitary Corps are

TABLE 3

Percentage distribution of alpha scores of officers in different arms of the service (from 16 camps)[1]

Score	Infantry	F. Artillery	Machine Gun Bn.	Engineers	Field Signal Bn.	Quartermaster Corps	Medical Corps	Dental Corps	Veterinary Corps	Sanitary Corps	Chaplains and School for Chaplains	Total	Total numbers
200–212	0.2	0.4	0.2	1.2	1.4	0.1	....	....	....	3.0	1.1	0.3	38
190–199	2.0	2.5	2.6	6.0	3.7	1.9	0.8	....	....	6.2	5.4	2.1	320
180–189	4.8	7.3	4.8	12.5	7.8	2.7	3.1	0.7	0.8	2.0	10.7	5.0	757
170–179	7.8	11.5	5.8	15.1	8.7	7.5	5.6	2.6	0.8	10.2	16.0	7.9	1201
160–169	10.3	13.8	13.6	18.5	12.1	8.1	7.6	5.7	2.4	15.3	10.7	10.4	1581
150–159	12.7	13.8	11.5	13.8	15.1	10.4	10.0	6.9	6.0	16.3	13.8	11.9	1810
140–149	12.2	14.3	11.7	12.2	10.6	12.4	10.7	11.6	9.1	8.2	8.5	11.9	1805
130–139	12.2	12.7	13.9	7.9	11.2	11.5	11.6	13.5	9.1	10.2	11.7	11.8	1785
120–129	10.5	8.3	12.5	4.2	8.4	11.5	11.6	12.8	16.2	9.2	9.5	10.3	1554
110–119	8.6	6.4	6.4	3.6	5.0	6.9	11.0	13.3	13.4	6.1	5.3	8.5	1287
100–110	6.5	3.6	5.4	2.6	5.6	9.1	8.9	12.1	8.3	3.1	2.2	6.7	1013
90–99	4.7	2.1	3.8	1.4	3.1	5.4	6.6	7.8	13.4	5.1	1.1	4.9	731
80–89	3.3	1.6	3.4	0.4	3.4	5.2	4.9	6.6	9.1	2.0	2.1	3.5	535
70–79	1.9	0.8	1.6	0.3	1.4	3.3	3.0	2.4	5.2	3.0	2.2	2.0	305
60–69	1.3	0.5	1.4	....	1.4	1.7	2.2	1.9	3.2	....	....	1.4	204
50–59	0.7	0.3	0.6	0.1	0.3	1.1	1.4	0.9	2.4	....	....	0.9	125
40–49	0.3	....	....	0.1	0.3	0.3	0.7	0.7	0.8	....	....	0.4	54
30–39	0.2	....	0.4	....	0.3	0.6	0.3	....	....	....	....	0.2	28
20–29	....	....	....	....	0.3	0.3	0.1	0.2	....	....	....	0.1	11
10–19	....	....	....	....	....	....	....	0.2	....	....	....	....	3
0–9	....	....	0.2	....	....	....	....	....	....	....	....	....	1
No. cases...	6942	1523	496	1026	357	756	3180	423	253	98	94	....	15148
Median.....	139.8	149.5	140.6	162.1	148.9	133.6	129.3	122.9	116.5	151.4	156.3	139.6	....

[1] Data obtained from Official Report, tables 392–397, pp. 848–852.

reversed, their order of increasing magnitude is identical with the order of increasing A and B grades in the arms of the service.

The distribution of alpha scores for the group of 2507 medical officers whose records constitute the material of this special report, as presented in table 4, agrees closely with that for the somewhat larger group of medical officers in table 3. The median scores of the two groups, it will be noted, differ by one-tenth point.

In connection with these distributions and median scores, the attention of the reader is invited to the very considerable differences in the intellectual status of the several corps (medical, dental, veterinary, sanitary), which are included in the Medical Department of the United States Army. The relation of these differences to the data for other arms of the service is significant, and in the following pages an attempt will be made to indicate what appear to be the chief reasons for the wide variations in intelligence among the principal corps.

TABLE 4

Alpha distribution of 2507 medical officers

Alpha score	Number	Percentage
200–204	3	0.1
190–199	22	0.9
180–189	77	3.0
170–179	131	5.3
160–169	195	7.8
150–159	250	10.0
140–149	267	10.6
130–139	287	11.4
120–129	276	11.0
110–119	285	11.4
100–109	227	9.1
90–99	171	6.8
80–89	121	4.9
70–79	76	3.1
60–69	53	2.1
50–59	37	1.5
40–49	19	0.8
30–39	7	0.2
20–29	2	0.1
10–19	1	0.0
Total	2507	....
Median	129.2	....

The quantitative differences in intelligence of groups of army officers indicated by total scores in examination alpha are undoubtedly important, but they are by no means so interesting either professionally or educationally as are the contrasts which appear when the results for examination alpha are presented by tests instead of by total scores. In the following section the data of examination are presented by tests, in order to indicate characteristic intellectual differences in the principal arms of the service.

Psychographs.—Examination alpha consists of eight separate tests (see page 467) which measure several types of intellectual function. The maximum score for the entire examination is 212 points distributed as follows among the tests: Test 1, 12 points; test 2, 20 points; test 3, 16 points; test 4, 40 points; test 5, 24 points; test 6, 20 points; test 7, 40 points; test 8, 40 points. The records of a group of approximately 15,000 officers of all arms of the service and of a group of approximately 3000 medical officers have been analyzed by tests in order that comparison might be made of the performance of medical officers on the several types of test with that of officers in general. The data for this comparison appear in tables 5, 6 and 7. Of these, table 5*a* gives the percentage distribution of scores for each alpha test of officers of all arms of the service, and table 5*b* the percentage of individuals achieving not more than the indicated score. This table serves as a standard with which the data for special groups may be compared. Table 6 similarly gives the percentage distribution of scores on each alpha test for medical officers. At the bottom of each table the median score for each test is entered.

The data by tests for the principal arms of the service are conveniently arranged in table 7, which gives the median score (50th percentile) on each test of examination alpha for seven special groups of officers as contrasted with the total officer group.

For convenience of comparison the median score of "all arms" of the service is taken as the 50th percentile, and the results for the several special groups are expressed in terms of the percentile distribution of "all arms." For example, the median score for medical officers on test 1 (8.7) falls at the 29.5 percentile on the distribution of scores of officers of all arms; the median for test 2 falls at the 36th percentile, etc., as indicated in table 7, and also in figure 2.

The surprising differences in performance for the several arms of the service on the separate tests of examination alpha are

TABLE 5a

Percentage distribution of scores on each alpha test of approximately 15,000 officers of all arms

Score	Test number							
	1	2	3	4	5	6	7	8
40	....	....	....	2.4	....	....	1.0	0.7
39	....	....	....	0.3	....	....	1.5	2.4
38	....	....	....	3.6	....	....	1.8	3.8
37	....	....	....	0.9	....	....	2.3	5.4
36	....	....	....	3.7	....	....	2.6	6.5
35	....	....	....	2.1	....	....	2.5	7.0
34	....	....	....	3.9	....	....	2.9	7.4
33	....	....	....	2.9	....	....	3.0	7.6
32	....	....	....	4.5	....	....	3.0	7.1
31	....	....	....	3.8	....	....	3.2	6.5
30	....	....	....	5.0	....	....	3.1	6.3
29	....	....	....	4.4	....	....	3.2	5.4
28	....	....	....	5.3	....	....	3.7	4.8
27	....	....	....	4.7	....	....	3.6	4.3
26	....	....	....	5.4	....	....	3.9	3.4
25	....	....	....	4.7	....	....	3.6	3.2
24	....	....	....	5.0	7.0	....	3.7	2.5
23	....	....	....	4.2	1.4	....	3.4	2.1
22	....	....	....	4.5	8.8	....	3.2	2.0
21	....	....	....	3.8	3.5	....	2.9	1.8
20	....	0.0	....	3.4	9.0	0.4	2.7	1.5
19	....	1.3	....	2.8	5.1	0.2	2.3	1.6
18	....	2.6	....	3.0	9.0	2.2	2.1	1.1
17	....	5.4	....	2.1	5.9	2.8	2.3	0.9
16	....	6.8	4.6	2.1	7.9	4.2	2.2	1.0
15	....	8.6	7.5	1.8	5.7	5.9	2.0	0.8
14	....	10.9	8.8	1.6	7.0	6.6	2.3	0.7
13	....	12.8	11.6	1.3	5.3	8.6	2.3	0.6
12	9.5	14.2	12.6	1.1	5.5	12.0	2.5	0.4
11	18.6	13.0	12.3	0.9	4.1	13.4	2.3	0.4
10	20.6	9.9	12.6	0.8	3.8	13.2	2.5	0.2
9	17.9	5.2	11.3	0.6	2.6	10.4	2.5	0.2
8	13.0	4.5	9.0	0.6	2.0	7.0	2.4	0.1
7	8.7	1.8	5.4	0.3	1.4	4.9	2.4	0.1
6	6.0	1.4	2.4	0.4	1.0	3.0	2.0	0.0
5	3.0	0.8	0.8	0.3	1.0	1.6	2.0	0.0
4	1.5	0.4	0.4	0.3	0.7	1.0	1.7	0.0
3	0.8	0.2	0.2	0.2	0.5	0.6	1.3	0.0
2	0.3	0.1	0.1	0.2	0.5	0.6	1.0	0.0
1	0.1	0.0	0.1	0.1	0.2	0.7	0.6	....
0	0.0	0.0	0.2	1.2	1.1	0.8	0.6	0.1
Median	9.9	12.9	11.6	26.5	17.0	11.5	23.6	31.7
Maximum	12	20	16	40	24	20	40	40

TABLE 5*b*

Percentile distribution of scores on each alpha test of approximately 15,000 officers of all arms

Score	Test number							
	1	2	3	4	5	6	7	8
40	.....	....	....	100.2	.....	.....	100.1	99.9
39	.....	....	....	97.8	.....	.....	99.1	99.2
38	.....	....	....	97.5	.....	.....	97.6	96.8
37	.....	....	....	93.9	.....	.....	95.8	93.0
36	.....	....	....	93.0	.....	.....	93.5	87.6
35	.....	....	....	89.3	.....	.....	90.9	81.1
34	.....	....	....	87.2	.....	.....	88.4	74.1
33	.....	....	....	83.3	.....	.....	85.5	66.7
32	.....	....	....	80.4	.....	.....	82.5	59.1
31	.....	....	....	75.9	.....	.....	79.5	52.0
30	.....	....	....	72.1	.....	.....	76.3	45.5
29	.....	....	....	67.1	.....	.....	73.2	39.2
28	.....	....	....	62.7	.....	.....	70.0	33.8
27	.....	....	....	57.4	.....	.....	66.3	29.0
26	.....	....	....	52.7	.....	.....	62.7	24.7
25	.....	....	....	47.3	.....	.....	58.8	21.3
24	.....	....	....	42.6	100.0	.....	55.2	18.1
23	.....	....	....	37.6	93.0	.....	51.5	15.6
22	.....	....	....	33.4	91.6	.....	48.1	13.5
21 •	.....	....	....	28.9	82.8	.....	44.9	11.5
20	.....	00.0	....	25.1	79.3	100.1	42.0	9.7
19	.....	69.9	....	21.7	70.3	99.7	39.3	8.2
18	.....	98.6	....	18.9	65.2	99 5	37.0	6.6
17	.....	96.0	....	15.9	56.2	97.3	34.9	5.5
16	.....	90.6	99.9	13.8	50.3	94.5	32.6	4.6
15	.....	83.8	95.3	11.7	42.4	90.3	30.4	3.6
14	.....	75.2	87.8	9.9	36.7	84.4	28.4	2.8
13	.....	64.3	79.0	8.3	29.7	77.8	26.1	2.1
12	100.0	51.5	67.4	7.0	24.4	69.2	23.8	1.5
11	90.5	37.3	54.8	5.9	18.9	57.2	21.3	1.1
10	71.9	24.3	42.5	5.0	14.8	43.8	19.0	0.7
9	51.3	14.4	29.9	4.2	11.0	30.6	16.5	0.5
8	33.4	9.2	18.6	3.6	8.4	20.2	14.0	0.3
7	20.4	4.7	9.6	3.0	6.4	13.2	11.6	0.2
6	11.7	2.9	4.2	2.7	5.0	8.3	9.2	0.1
5	5.7	1.5	1.8	2.3	4.0	5.3	7.2	0.1
4	2.7	0.7	1.0	2.0	3.0	3.7	5.2	0.1
3	1.2	0.3	0.6	1.7	2.3	2.7	3.5	0.1
2	0.4	0.1	0.4	1.5	1.8	2.1	2.2	0.1
1	0.1	0.0	0.3	1.3	1.3	1.5	1.2	0.1
0	0.0	0.0	0.2	1.2	1.1	0.8	0.6	0.1
Median	9.9	12.9	11.6	26.5	17.0	11.5	23.6	31.7
Maximum	12	20	16	40	24	20	40	40

TABLE 6

Percentage distribution of scores on each alpha test of approximately 3,000 medical officers

Score	Test number							
	1	2	3	4	5	6	7	8
40	....	....	....	1.7	...	....	0.4	0.8
39	....	....	....	0.4	...	....	0.9	2.3
38	....	....	....	3.5	...	....	0.6	4.2
37	....	....	....	1.0	...	....	1.3	5.7
36	....	....	....	4.0	...	....	1.9	7.2
35	....	....	....	2.4	...	....	1.5	6.6
34	....	....	....	3.5	...	....	1.7	7.2
33	....	....	....	3.3	...	....	1.9	7.1
32	....	....	....	4.9	...	....	2.0	6.3
31	....	....	....	3.7	...	....	2.0	5.9
30	....	....	....	3.9	...	....	2.1	5.9
29	....	....	....	4.4	...	....	2.4	4.7
28	....	....	....	5.1	...	....	2.3	4.7
27	....	....	....	4.7	...	....	2.7	3.8
26	....	....	....	4.6	...	....	3.2	3.6
25	....	....	....	5.0	...	....	2.5	3.2
24	....	....	....	5.3	4.4	....	3.4	2.3
23	....	....	....	4.4	1.5	....	3.2	2.2
22	....	....	....	4.2	7.0	....	3.2	1.9
21	....	....	....	4.2	3.4	....	2.7	2.0
20	....	0.1	....	3.1	6.9	0.2	2.5	1.9
19	....	0.5	....	2.6	5.6	0.3	2.5	1.9
18	....	1.1	....	2.6	9.0	0.6	2.3	1.1
17	....	2.3	....	2.3	6.3	1.0	2.5	1.0
16	....	4.0	2.5	2.0	8.1	2.0	2.5	1.3
15	....	5.6	5.2	1.5	6.2	2.9	2.3	1.2
14	....	8.3	7.4	1.6	7.1	4.3	3.3	0.9
13	....	11.9	9.6	1.2	5.8	5.7	3.3	0.9
12	3.6	14.7	11.7	1.1	5.7	10.2	3.3	0.3
11	8.5	13.3	11.0	0.9	4.4	13.6	2.8	0.4
10	15.1	13.6	13.2	0.9	4.2	15.7	3.5	0.3
9	18.2	9.5	13.1	0.6	3.4	12.7	3.3	0.3
8	17.2	6.0	11.6	0.6	2.4	10.4	2.7	0.1
7	13.8	4.3	7.8	0.5	1.7	7.2	3.8	0.2
6	11.0	2.4	3.6	0.4	1.3	4.6	3.3	0.1
5	6.3	1.2	1.4	0.3	1.3	2.4	3.4	0.1
4	3.6	0.7	0.7	0.3	0.9	1.3	3.3	0.1
3	1.9	0.2	0.4	0.3	0.7	1.0	2.5	0.0
2	0.6	0.2	0.2	0.1	0.8	1.2	2.1	0.0
1	0.3	0.1	0.1	0.2	0.2	1.2	1.5	0.0
0	0.0	0.0	0.3	2.4	1.7	1.7	1.2	0.1
Median	8.7	11.9	10.8	26.3	16.3	10.4	17.7	31.6
Maximum	12	20	16	40	24	20	40	40

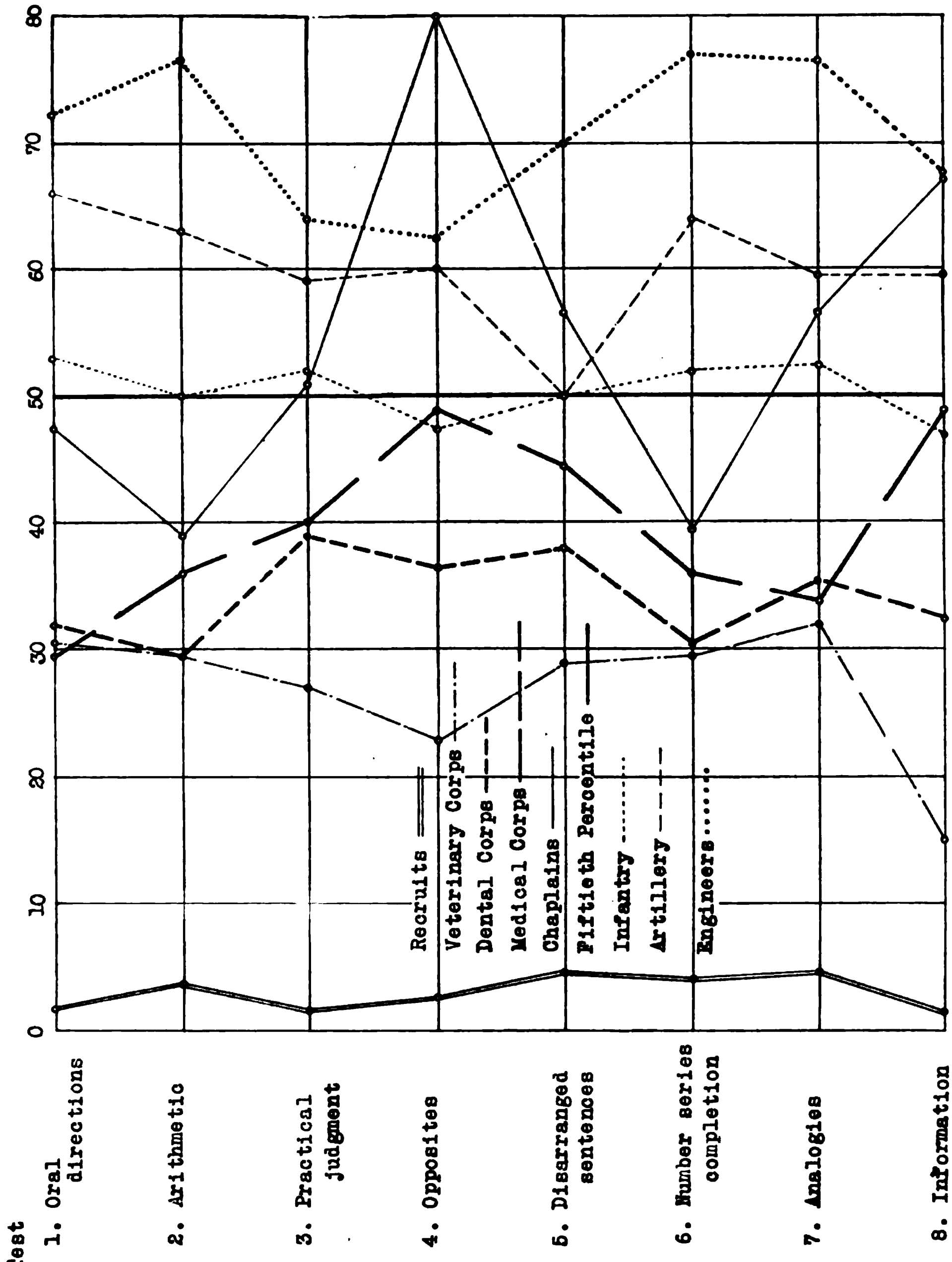

Fig. 2. Psychographs for representative groups of military officers.

TABLE 7

Median (50th percentile) score on alpha tests of officers in different arms of the service, compared with standard group of officers of all arms.

Arm of the service	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Total
Medical officers	8.7	11.9	10.8	26.3	16.3	10.4	17.7	31.6	129.3
(Percentile reached)	(29.5)	(36.0)	(40.0)	(49.0)	(44.5)	(36.0)	(34.0)	(49.0)	
Infantry	10.1	12.9	11.8	26.0	17.0	11.6	24.2	31.2	139.8
(Percentile reached)	(53.0)	(50.0)	(52.0)	(47.5)	(50.0)	(52.0)	(52.5)	(47.0)	
Artillery	10.7	13.9	12.3	28.6	17.0	12.5	26.2	33.0	149.5
(Percentile reached)	(66.0)	(63.0)	(59.0)	(60.0)	(50.0)	(64.0)	(59.5)	(59.5)	
Engineers	11.0	15.1	12.7	29.1	19.9	13.9	31.0	34.2	162.1
(Percentile reached)	(72.0)	(76.5)	(64.0)	(62.5)	(70.0)	(77.0)	(76.5)	(67.5)	
Dental	8.9	11.4	10.7	23.7	15.2	10.0	18.3	28.7	122.9
(Percentile reached)	(32.0)	(29.5)	(39.0)	(36.5)	(38.0)	(30.5)	(35.5)	(32.5)	
Veterinary	8.8	11.4	9.8	20.5	13.8	9.9	16.6	23.8	116.5
(Percentile reached)	(30.5)	(29.5)	(27.0)	(23.0)	(29.0)	(29.5)	(32.0)	(15.0)	
Chaplains	9.8	12.1	11.7	33.0	18.0	10.7	25.3	34.0	156.3
(Percentile reached)	(47.5)	(39.0)	(51.0)	(80.0)	(56.5)	(39.5)	(56.5)	(67.0)	
All arms	9.9	12.9	11.6	26.5	17.0	11.5	23.6	31.7	139.6
(Percentile reached)	(50.0)	(50.0)	(50.0)	(50.0)	(50.0)	(50.0)	(50.0)	(50.0)	(50.0)
Maximum score for test	12	20	16	40	24	20	40	40	212

visualized in figure 2, which indicates, among other things, that the score of medical officers is in no case as high as the median score of all arms of the service which is represented in the figure by the heavy 50th percentile line. The curves of figure 2 are known as psychographs. It is peculiarly interesting to note that the psychograph of medical officers is very nearly the inverse of that for engineers. In other words, where the engineer tests particularly well the medical officer tests poorly, and conversely. The psychograph for the infantry corresponds most nearly to the standard. This is partly because it is by far the largest special group in the total and therefore affects the standard most markedly. The chaplains' psychograph is notable because of the extreme variation in scores; thus on test 4 (opposites) the chaplains achieve a median score which is much higher than that of any other group, whereas on tests 2 (arithmetic) and 6 (number series completion) they fall considerably below the median for all officers. It is worthy of note that for only three groups, namely, the medical, dental and veterinary, do the psychographs as a whole fall below the standard for comparison.

In order to discover whether the psychograph for medical officers presented in figure 2 is really characteristic of the professional group, the group was subdivided according to the principal specialties represented, of which there are nine, as listed in table 8. Of these, seven are represented in figure 3. This figure shows a striking resemblance among the psychographs of the special medical groups and justifies the statement that the medical psychograph is characteristic of the professional group. The fact that the

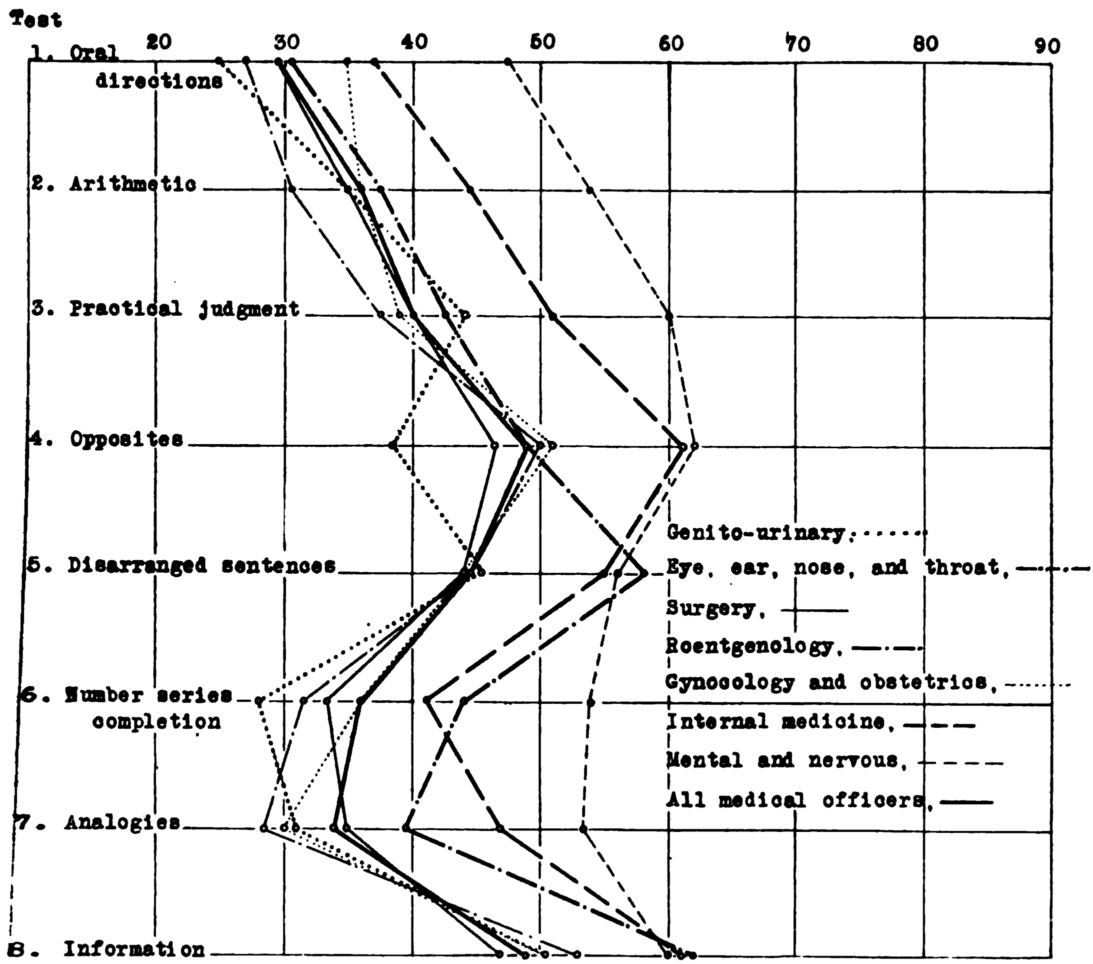

Fig. 3. Psychographs for medical specialists.

"mental and nervous" group stands well above the others is explainable on the basis of difference in the method of selection for appointment to the military service. It happens that the neuropsychiatric specialists were carefully selected and recommended to the Medical Department by a special committee which operated under the auspices of the National Committee for Mental Hygiene. The presumption is that the efforts of this committee eliminated a large proportion of intellectually low grade and professionally incompetent men.

On the chance that the psychograph for the medical profession

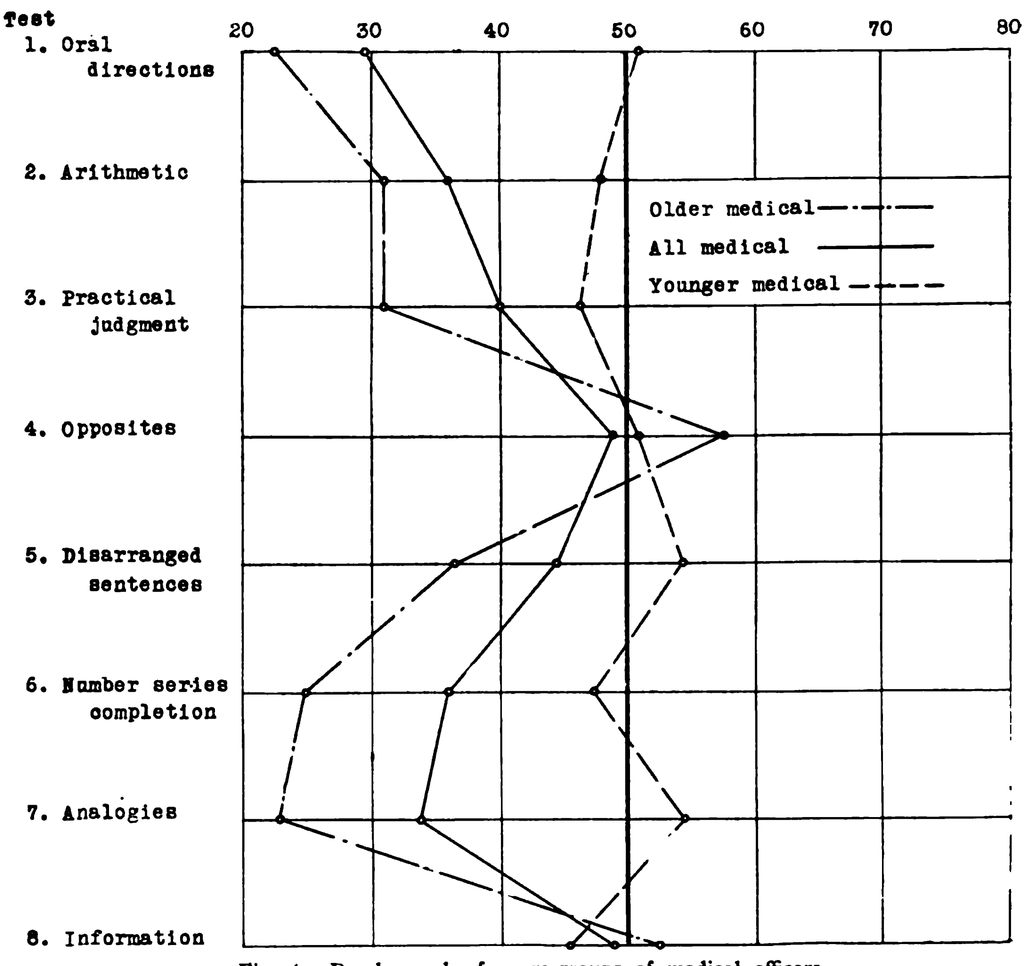

Fig. 4. Psychographs for age-groups of medical officers.

might vary significantly with age, the data for two small groups of medical officers were assembled for comparison. The one of these groups consisted of 140 individuals aged 26 years or less, the other of 144 individuals aged 50 years or more. The psychographs of

TABLE 8

Median (50th percentile) scores on alpha tests of specialists within the medical profession, compared with standard group of officers of all arms

Specialty	No. cases	Median score on alpha tests								Total alpha
		1	2	3	4	5	6	7	8	
Anesthesia	35	9.1	11.1	10.1	26.8	15.6	11.1	13.5	31.6	130.8
(Percentile reached)		(35.0)	(25.5)	(31.0)	(51.5)	(40.0)	(45.5)	(25.0)	(49.0)	
Eye	46	9.1	12.0	11.3	27.8	16.6	10.8	19.0	34.3	140.0
(Percentile reached)		(35.0)	(37.5)	(46.5)	(56.5)	(47.0)	(41.0)	(37.0)	(68.5)	
Eye, ear, nose and throat	175	8.5	11.5	10.6	26.5	16.3	10.1	14.9	32.1	128.3
(Percentile reached)		(27.0)	(30.5)	(37.5)	(50.0)	(44.5)	(31.5)	(28.5)	(53.0)	
Genito-urinary diseases	77	8.4	11.8	11.1	24.2	16.4	9.8	16.3	31.7	124.4
(Percentile reached)		(25.0)	(35.0)	(44.0)	(38.5)	(45.5)	(28.0)	(31.0)	(50.5)	
Gynecology and obstetrics	88	9.1	11.9	10.7	26.7	16.2	10.4	15.8	31.7	128.1
(Percentile reached)		(35.0)	(36.0)	(39.0)	(51.0)	(44.0)	(36.0)	(30.0)	(50.5)	
Internal medicine	178	9.2	12.5	11.7	28.8	17.8	10.8	22.8	33.2	143.6
(Percentile reached)		(37.0)	(44.5)	(51.0)	(61.0)	(55.0)	(41.0)	(47.0)	(61.0)	
Mental and nervous diseases	54	9.8	13.2	12.4	29.0	17.9	11.7	24.6	33.1	143.0
(Percentile reached)		(47.5)	(54.0)	(60.0)	(62.0)	(56.0)	(54.0)	(53.5)	(60.0)	
Roentgenology	54	8.8	12.0	11.0	26.3	18.2	11.0	20.0	33.3	136.0
(Percentile reached)		(30.5)	(37.5)	(42.5)	(49.0)	(58.0)	(44.0)	(39.5)	(62.0)	
Surgery	640	8.7	11.8	10.8	25.8	16.2	10.3	18.0	31.2	127.4
(Percentile reached)		(29.5)	(35.0)	(40.0)	(46.5)	(44.0)	(33.5)	(35.0)	(47.0)	
All medical officers	3165	8.7	11.9	10.8	26.3	16.3	10.4	17.7	31.6	129.3
(Percentile reached)		(29.5)	(36.0)	(40.0)	(49.0)	(44.5)	(36.0)	(34.0)	(49.0)	
Eye, ear, nose and throat, promoted	35	9.6	11.7	10.9	29.5	18.2	10.7	16.6	33.1	
(Percentile reached)		(34.0)	(33.5)	(41.5)	(64.5)	(58.0)	(39.5)	(32.0)	(60.0)	
Eye, ear, nose and throat. Not known to be promoted	140	8.1	11.4	10.5	25.9	15.5	9.9	14.0	31.6	
(Percentile reached)		(21.0)	(29.5)	(36.5)	(47.0)	(39.5)	(29.5)	(26.0)	(49.0)	

these two medical groups (as appears in figure 4) differ in two obviously important respects. That for the younger group closely approximates the 50th percentile standard and is similar in form to the psychograph for infantry officers. That for the older group falls even farther below the standard than the psychograph for all medical officers and its form is an accentuation of the peculiarities of the medical psychograph which has been considered in an earlier paragraph.

Comparison of figures 2 and 4 indicates a certain similarity between the psychograph of chaplains (figure 2) and that of older medical officers (fig. 4). The median age of the chaplains is 31.8 years. It is possible that a group of engineers of approximately the same age as the medical officers would yield a psychograph similar to theirs and radically different from that of the army engineers. It appears, then, that age may influence the form of psychograph.

The influence of language habits, in relation to age, appears in the results for the "opposites" test. The score for this test, as also for the "information" test, is larger for the older medical officers.

The psychographs of such professional groups as medical, veterinary, engineer, chaplains, may prove to have either educational or vocational significance, or possibly both. Should further inquiry indicate that they are characteristic of the student groups which enter the several types of school, respectively, it would seem that they might serve as partial basis for vocational advice. If, on the contrary, they are the product of professional training and experience, they should prove useful in connection with educational methods. In any event, it is clear that this subject deserves further and immediate attention, since it may possibly yield information which will serve to improve the status of the medical profession either through more satisfactory selection of medical students or through their more effective training.

Age of Medical Officers

It was early suggested that greater age of medical officers might be responsible for their relatively low intelligence rating. The facts presented on pp. 480, 481 and in this section wholly justify this surmise. In the first place it appears from table 9 that the median age of officers of the Medical Corps is 37.6 years, whereas that of all officers is 28.8. The nearest approach to the median age of medical

TABLE 9

Age distribution of officers. Figures are percentage distributions for different arms of the service[1]

Arm	Age-group (years)									Median age	Number of cases
	20 and less	21–22	23–24	25–26	27–28	29–30	31–40	41–50	51–60		
Infantry	0.3	8.9	19.8	19.7	15.1	11.1	20.0	4.7	0.4	27.2	6842
Artillery	0.1	11.3	23.4	20.4	15.6	12.2	15.3	1.7	0.0	26.5	1507
Machine gun battalions	0.0	10.6	21.2	18.9	16.2	8.5	19.9	4.7	0.0	26.9	493
Engineers	0.1	6.7	16.9	17.2	16.0	12.2	25.6	4.5	0.5	28.1	984
Field Signal Corps	0.3	5.5	14.7	16.4	13.2	13.5	27.9	8.6	0.3	29.0	350
Quartermaster Corps	0.1	4.0	13.2	15.4	16.6	12.4	25.0	11.9	1.1	29.1	747
Medical Corps	0.0	0.0	2.2	4.8	7.3	8.1	42.0	30.1	5.6	37.6	3090
Dental Corps	0.0	3.9	16.8	25.0	16.8	14.2	17.2	6.0	0.0	27.5	413
Veterinary Corps	0.0	3.2	13.6	16.7	22.0	15.1	26.7	2.4	0.4	28.5	251
All officers	0.2	6.4	15.2	15.9	13.8	10.9	25.8	10.6	0.1	28.8	15385

officers is that of the Quartermaster Corps, 29.1. It thus appears that the median medical officer is approximately 9 years older than his median military associate.

That intelligence is related to age has been demonstrated by the analysis of mental measurements made in the army. In general the intelligence rating tends to diminish with age. That this is due to age alone and not to selectional processes operating in connection with age is by no means certain. The above statements are based upon such data as are reproduced in the accompanying tables 10 and 11. No special study, in addition to the comparison instituted in figure 4, has been made of the relation of age to intelligence in the particular group of medical officers under consideration. From table 10 it appears that there is no regular or significant decrease in intelligence rating from 20 to 26 years. Thereafter to the age of 60 there is a marked decrease. The median for the age group 31 to 40 years (within which the age of medical officers falls) is 133 points, whereas that for the age group of officers in general is about 143 points. Particularly significant are the data of table 11 for the large group of medical officers examined at Camp Greenleaf with army examination *a*. It should be mentioned

[1] Official report, table 372, p. 818.

that the median scores of this table are much larger than those of previous tables because the maximum score for examination *a* is 414 points, whereas that for examination alpha is 212 points. These medians indicate that a medical officer above 30 years of age is at a disadvantage in the intelligence examination *a*, as compared with an officer under 30 years of age. Finally, the following

TABLE 10

Relation of age to intelligence for 15,385 officers given examination alpha[1]

Intelligence rating	20 and less	21–22	23–24	25–26	27–28	29–30	31–40	41–50	51–60	60 up
A	66.8	66.9	63.6	60.3	60.3	57.4	49.1	40.0	34.0	62.5
B	29.2	24.7	27.7	28.3	25.9	28.1	30.1	31.4	32.7	25.0
C+	4.2	6.5	7.8	9.7	11.1	11.6	15.5	21.1	21.2	0.0
C	.....	1.5	1.2	1.8	2.2	2.4	4.9	6.4	10.2	12.5
C—	.....	0.1	0.1	.....	0.1	0.1	0.6	0.7	2.0	.....
D	.....	.....	.....	.....	.....	0.1	.....	0.3	.....	.....
D—	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Median	150	146	146	147	143	141	133	125	120	140
Number of cases	24	985	2,330	2,434	2,101	1,665	3,963	1,635	240	8
Percent of total number of cases	0.2	6.4	15.2	15.9	13.8	10.9	25.8	10.6	1.6	0.1

coefficients of correlation between age and score in examination *a* are offered in justification of the conclusion that age is negatively correlated to a significant degree with intelligence rating:[2]

5,404 medical officers, Camp Greenleaf	—0.192
2,475 medical officers, Camp Greenleaf, 21–30 years	—0.063 (P. E. 0.013)
3,267 medical officers, Camp Greenleaf, 30–60 years	—0.192 (P. E. 0.011)
146 medical officers, Camp Devens	—0.011
308 infantry officers, Camp Devens	—0.120

Four principal causes have been suggested for the relatively low intelligence rating of medical officers. These are, first, lack of agility and speed in the examination because of age; second, tendency to work carefully and accurately as a result of professional training and experience; third, special characteristics of tests rendering them easier for men of mathematical and mechanical training

[1] Official report, table 366, p. 814.
[2] *Ibid.*, p. 817.

TABLE 11

Relation of intelligence to age of 5,742 medical officers, Camp Greenleaf, given examination *a*[1]

2,475 of draft age

Statistical measurement	Age									
	21	22	23	24	25	26	27	28	29	30
Median	232	273	269	273	277	267	265	266	261	258
Number of cases	11	52	132	241	303	376	361	352	338	309

3,267 over draft age

Statistical measurement	30–31	32–33	34–35	36–37	38–39	40–41	42–43	44–45	46–47	48–49	50–51	52–53	54–55
Median	254	259	262	252	255	255	246	235	242	237	223	214	212
Number of cases	582	330	257	301	301	305	279	241	219	172	131	82	63

than for medical officers; and fourth, method of selection for military appointment. These four possible factors will be considered briefly in order.

It is granted that increasing age tends to diminish the score in examinations *a* and alpha. The statistical data clearly indicate, however, that age is only partly responsible for the relative position of the Medical Corps.

The importance of agility and speed in the tests is generally overestimated by the subject of examination. It would seem reasonable to suppose that medical officers on account of their greater age would be placed at a disadvantage by comparison with other officers because of the limited time allowed to work on each test. If this were actually the case those tests which are most closely timed, and therefore most nearly speed tests, rather than achievement tests, should show relatively the lowest scores for medical officers. This is not the case. Comparison of the numbers of officers who complete a test within the time limit shows that the allowance is relatively liberal for tests 1, 5, 7 and 8, whereas for tests 2, 3, 4 and 6 the time allowance is so short that only a small proportion of officers can finish.

The medical psychograph of figure 2 indicates that of the four

[1] Official report, table 369, p. 816.

liberally timed tests, number 1 and number 7 are the most difficult, and number 8 one of the easiest for medical officers. Test 5 also is relatively easy. Of the speed tests, numbers 2 and 6 are relatively difficult, whereas test 4 ranks with test 8 as one of the easiest of all. Test 3 also is relatively easy. It is evident, then, that a short time allowance is not a factor which renders the tests of examination alpha more difficult for medical officers than for other army officers.

There is no evidence whatever that medical officers worked more carefully and accurately than other officers and as a result failed to achieve as high scores as those officers who worked more rapidly. In general it has been found that speed and accuracy in tests of intelligence are highly correlated. It is therefore wholly improbable that the relative rank of the Medical Corps is affected to any considerable extent by professional training and experience.

Evidence is lacking also for differences in applicability of the tests to special army groups. Examination of the preceding tables and curves shows that the examination as a whole is fair to very diverse individuals and groups because of the variety of elements combined in it. In this connection careful study of table 7 and figure 2 is desirable. If the examination in question had depended upon the exercise of a single type of intellectual function the possibility of unfairness would be obvious. Instead it depends upon the exercise of all of the principal intellectual functions and employs those functions in various combinations for response to a large number of test items in each of eight markedly different types of test.

The method of selection for military appointment in the Medical Department differed radically from that of other arms of the service. For the Medical Corps, as well as the Dental, Veterinary and Sanitary Corps, applications were received from qualified civilians and acted on either favorably or unfavorably according to physical condition, age and professional qualifications. Aside from the physical examination, and in certain instances a professional examination of candidates for the Medical Corps, no special tests were given to measure the ability or professional competence of the individual, and though many of the candidates were sent to officers' training schools for rapid or intensive training, this was done in the Medical Department after military appointment instead of before. In the case of the other arms of the ser-

vice a large proportion of candidates for appointment were sent to officers' training schools prior to appointment and were there subjected to a series of examinations, the effect of which was to eliminate the less intelligent as well as those otherwise less competent for military service. Data of psychological examinations show a high correlation between intelligence and success in achieving military appointment in officers' training schools. There can be no doubt that the method of selection employed by the Medical Department of the army worked to the disadvantage of the medical profession so far as intellectual status is concerned. Had the exigencies of the situation permitted the Medical Department to utilize a probational period as did the other corps, the intelligence of its personnel would have been much higher.[1]

It is reasonably certain, then, that age and method of military selection are largely responsible for the relatively low intelligence of medical officers. The Medical Department obtained the services alike of the best and the poorest members of the profession, but the proportion of intellectually inferior and professionally incompetent men was much larger in this group, for the reason indicated above, than in many other arms of the service. These explanations of the status of medical officers must not be taken as a justification of that status. It is wholly clear that the medical profession has a large number of men who are intellectually incompetent and who should not have been allowed to study medicine, or having studied it, should not have been licensed as practitioners. The army was constrained to accept their services because of an imperative need of medical officers. Ordinarily their applications would have received scant consideration.

To the credit of the Medical Department of the army is the fact that rank is more highly correlated with intelligence in the case of medical officers than for any other military group. The intellectually low grade men of the medical profession are almost invariably of low military rank, and promotion depends alike upon intellectual ability and professional value.

Education of Medical Officers

The schooling reported on the psychological examination record

[1] At Camp Greenleaf, the medical officers' training camp, beginning early in 1918, a professional examination and also the army psychological examination were utilized to eliminate the incompetent. Doubtful cases were re-examined after a period of intensive training. This definitely indicates that the Medical Department appreciated the desirability of rigorous examinations in association with a probational period.

by all officers yields a median of 14.7 years. If 8 years be allowed for grammar school and 4 years for high school, this median represents 2.7 years of college or professional training. Put in another way, the average army officer was nearly through the third year in college, technical or professional school, when his formal education ended. The group of medical officers reported a median schooling of 15.8 years, which is equivalent to 3.8 years beyond high school. As a rule these years were devoted to professional instead of collegiate or pre-medical study.

The principal available facts concerning the schooling of the chief arms of the service appear in table 12, which gives the distribution for several arms of the service and also for three rank-groups in the Medical Corps, as well as the medians for each. According to this table the medical group has the most schooling, the Quartermaster Corps the least schooling, of the several arms of the service compared. Yet their performances on examination alpha are practically identical. Between medical officer and engineer officer there is one-half year difference in favor of the former.

For the special medical group which has been intensively studied, data concerning education, both pre-medical and medical, are assembled in table 13. It is evident from the figures that the pre-medical education ordinarily does not exceed high school training, and that the professional training adds nearly four years to the total.

Figure 5 visualizes the distribution of schooling in case of recruits, Quartermaster, Engineer and Medical Corps.

The relation of intelligence to date of education, as indicated by table 14, is worthy of consideration. The median intelligence increases with approach to the present. This is in part due to age of the individuals, since the earlier graduates would show somewhat lower scores than the later graduates, but it is also due in part to the abandonment of several poor medical schools following the publication of Flexner's[1] report on the status of medical education in the United States, and the increase in educational requirement for entrance to medical schools.

Professional Experience of Medical Officers

The professional experience of this group of 2500 medical officers, previous to military appointment, is recorded statistically in table

[1] Abraham Flexner, "Medical Education in the United States and Canada." New York, Carnegie Foundation for the Advancement of Teaching, 1910.

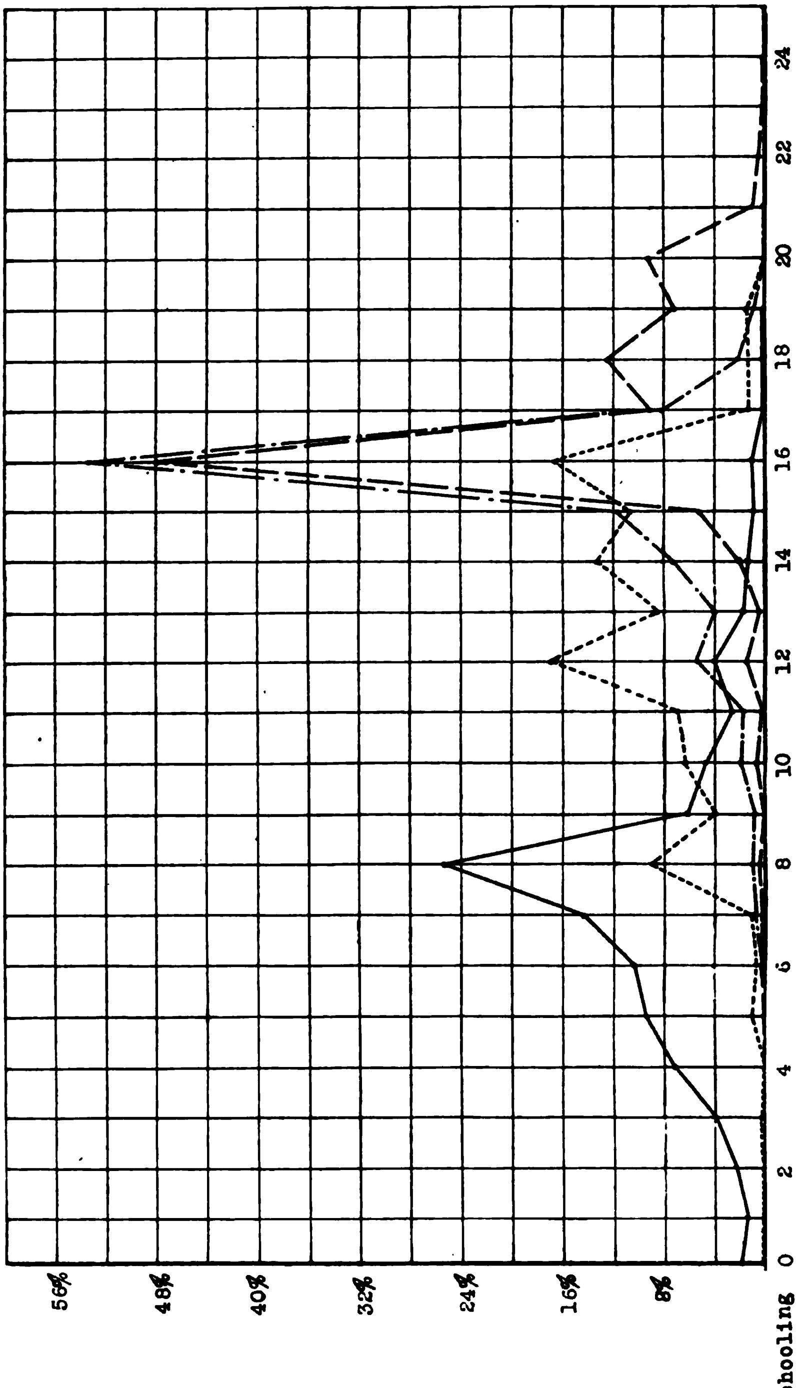

Fig. 5. Period of schooling of important military groups. Recruits, ——; Quartermaster Corps, ... ; Engineer Corps, —·—·; Medical Corps, — — —

TABLE 12

Length of schooling reported by officers in different arms of the service and by different ranks in the medical corps

Yrs. schooling	Infantry	Artillery	Engineer	Quartermaster	Medical	Dental	Veterinary	Total	Medical: 1st Lts.	Medical: Captains	Medical: Major and above
25	....	....	...	...	1	...	...	1	....	1	...
24	1	....	...	...	2	...	...	3	2	...	...
23	....	....	...	...	3	...	...	3	3	...	...
22	2	....	...	...	13	...	...	16	6	7	...
21	1	1	...	...	27	...	...	34	16	10	1
20	6	2	1	...	242	...	1	260	149	79	14
19	90	22	4	8	187	6	2	337	107	67	13
18	132	40	10	8	318	9	12	554	197	111	10
17	177	60	37	8	234	21	12	592	150	77	7
16	1486	470	238	100	1230	113	43	3894	799	366	65
15	778	181	53	64	136	159	140	1604	62	67	7
14	809	154	33	80	57	8	...	1247	27	26	4
13	487	79	18	51	12	2	...	1700	11	...	1
12	854	124	24	102	41	9	...	1246	26	13	2
11	337	29	8	42	8	3	...	460	2	6	...
10	328	35	9	38	20	2	11	485	4	16	...
9	228	18	4	24	1	1	3	318	1	...	...
8	305	16	5	54	13	...	5	443	7	5	1
7	39	4	3	7	6	...	...	64	3	3	...
6	37	4	1	4	4	...	...	51	3	1	...
5	18	3	...	6	3	...	...	31	3	...	...
4	16	3	...	...	1	...	...	22	....	...	1
3	14	4	...	1	....	...	...	20	....	...	...
2	5	1	...	...	....	...	...	6	....	...	...
1	1	....	...	...	....	...	...	1	....	...	...
0	3	....	...	1	....	...	...	4	....	...	...
Total	6154	1255	448	598	2559	334	229	12396	1576	857	126
Median	13.5	14.8	15.3	12.4	15.8	14.9	14.7	14.7	15.8	15.8	15.7

15. The largest single group had from 10 to 14 years' experience, while the median period is slightly in excess of 11 years.

In this respect the Medical Corps is unique, for no other arm of the service, not excepting the Engineer, Dental and Veterinary, has half the professional experience of this group. It is undoubtedly true that this marked difference in length of professional experience, coupled with age, affects not only the intelligence score of the medical officer, but also the character of his psychograph.

TABLE 13

Distribution of length of pre-medical and of total education of medical officers

Years	Pre-medical education		Total education	
	Number	Percentage	Number	Percentage
24	...	.....	2	0.09
23	...	.....	1	0.04
22	...	.....	4	0.2
21	...	.....	36	1.5
20	...	.....	293	12.5
19	1	0.04	250	10.7
18	7	0.3	308	13.1
17	32	1.3	310	13.2
16	485	20.5	744	31.6
15	148	6.2	288	10.6
14	267	11.2	111	4.7
13	295	12.4	32	1.4
12	826	34.8	12	0.5
11	199	8.4	5	0.2
10	92	3.9	...	.....
9	20	0.8	...	.....
8	2	0.1	...	.....
Not given	133	.....	152	.....
No. cases	2507	.....	2507	.....
Median........	12.16	.....	16.07	.....

Geographical Facts and Relations

The medical officers under consideration were drawn from all parts of the United States, but not in proportion to the number of practitioners in different localities. Instead, the records used for this report come largely from camps in which medical officers were most frequently examined. It happens, however, that every state in the union except Wyoming is represented in the group. The states most numerously represented are New York, Illinois, Ohio and Pennsylvania. Those least represented are Nevada, New Mexico and Delaware. Because of the small representation of certain states it was necessary to group the states for statistical purposes as indicated in table 16.

Locational intelligence.—For these several sections of the country interesting and valid differences in intelligence, experience, earn-

TABLE 14

Alpha distributions of groups graduated in different years

Alpha score	1880–85	1886–90	1891–95	1896–1900	1901–05	1906–10	1911–15	1916–18	Years not known and non-graduates	Total
205–212	..	..	..	..	..	..	..	..	..	...
200–204	..	..	..	1	1	..	..	1	..	3
190–199	..	..	3	1	7	1	7	3	..	22
180–189	1	1	2	10	19	21	15	7	..	76
170–179	..	1	4	19	16	25	39	27	..	131
160–169	..	3	7	25	39	48	45	27	1	195
150–159	..	7	19	29	57	51	56	29	2	250
140–149	4	8	15	35	60	56	53	35	1	267
130–139	3	7	19	33	57	57	77	34	..	287
120–129	..	8	18	40	54	68	62	25	1	276
110–119	..	3	19	37	63	63	68	31	1	285
100–109	..	9	16	30	45	63	50	13	1	227
90–99	1	3	9	26	38	39	43	12	1	172
80–89	1	2	12	28	31	21	19	7	..	121
70–79	..	3	9	11	18	17	14	3	1	76
60–69	..	4	3	8	12	16	8	1	1	53
50–59	..	..	5	6	14	6	6	..	..	37
40–49	1	1	4	4	1	5	2	1	..	19
30–39	..	..	1	..	2	1	2	..	1	7
20–29	..	..	..	..	1	..	1	..	..	2
10–19	..	..	1	..	..	..	..	..	..	1
Total	11	60	166	343	535	558	567	256	11	2507
Median	138.75	126.25	121.3	124.8	127.9	127.1	131.0	140.3	117.5	129.2

TABLE 15

Distribution of experience of 2392 medical officers

Years' experience	Number	Percentage
25 years and over	137	5.7
20–24	237	9.9
15–19	399	16.7
10–14	538	22.5
7–9	321	13.4
4–6	325	13.6
1–3	302	12.6
0	133	5.6
Total[1]..........	2392	....
Median.........	11.07 years	....

[1] Experience was not indicated by 115 of the 2507 medical officers.

TABLE 16

States included in each section, with number of cases

State	No. cases: Residence	No. cases: Certificate	No. cases: College
NORTHEAST			
Maine	17	15	9
New Hampshire	14	10.	14
Vermont	8	16	29
Massachusetts	138	152	124
Rhode Island	10	9	0
Connecticut	22	15	9
New York	276	257	272
Total	485	474	457
ATLANTIC			
New Jersey	50	30	0
Pennsylvania	193	183	253
Delaware	3	5	0
Maryland	28	34	147
Virginia	20	30	42
West Virginia	30	19	0
District of Columbia	11	6	23
Total	335	307	465
SOUTHERN			
Georgia	47	48	52
Florida	15	11	0
Alabama	37	41	21
Mississippi	46	45	21
Louisiana	29	32	51
Arkansas	3	22	6
Oklahoma	33	16	4
Texas	57	48	19
New Mexico	7	4	0
Total	274	267	154
SOUTH CENTRAL			
North Carolina	19	20	6
South Carolina	14	16	9
Kentucky	67	77	133
Tennessee	52	62	129
Total	152	175	277
NORTH CENTRAL			
Ohio	194	190	191
Michigan	65	69	75
Minnesota	64	51	44
Wisconsin	61	56	29
North Dakota	9	10	0
South Dakota	14	13	0
Total	407	389	339
CENTRAL			
Indiana	109	100	58
Illinois	220	278	393
Iowa	86	88	56
Missouri	115	114	146
Kansas	42	36	50
Nebraska	44	45	43
Total	616	661	746
WESTERN			
Oregon	37	31	16
Washington	47	25	0
Montana	21	15	0
Idaho	8	7	0
Wyoming	0	0	0
California	85	50	43
Nevada	0	1	0
Utah	9	7	0
Arizona	21	0	0
Colorado	24	16	10
Total	252	152	69

ings and degree of specialization appear. The outstanding differences are those in intelligence as measured by examination alpha. These are indicated by the median scores and grades of table 17

TABLE 17

Median alpha scores of doctors from different sections of the country

Section	Residence			Certificate			Graduation		
	No. cases[1]	Score	Grade	No. cases	Score	Grade	No. cases	Score	Grade
Northeast	485	138.8	A	474	138.1	A	457	139.9	A
Atlantic	335	126.1	B	307	124.7	B	465	129.9	B
South Central	152	102.3	C+	175	104.4	C+	277	105.6	B
Southern	274	115.2	B	267	116.8	B	154	117.6	B
North Central	407	135.1	A	389	135.3	A	339	131.3	B
Central	616	126.0	B	661	127.4	B	746	129.3	B
Western	252	140.0	A	152	137.7	A	69	139.6	A
Total	2521	129.2	B	2419	128.9	B	2507	129.2	B

and by the detailed distribution of table 18. They are also visualized in part by figure 6.

The median scores for the seven sections of the country range from 102 points in the South central, including North and South Carolina, Kentucky and Tennessee, to 139 and 140, respectively, in the Northeast and the Pacific and Rocky Mountain states. The Atlantic central states stand higher than the Southern but lower than the North central. Corresponding groupings were made on the basis of the state from which the individual is certified and also in which he was graduated. These groupings yield results very similar to the above.

The data of the tables tend to confirm Cattell's study of the distribution of professional ability ("American Men of Science"), in which he demonstrated that New England and California were supplying eminent men of science in larger proportion than were other regions. The groups of medical officers from the Northeast and the Pacific coast are nearly identical in intelligence and similar in other respects as indicated by the several tables of this section.

[1] For number of cases from individual states, see table 16.

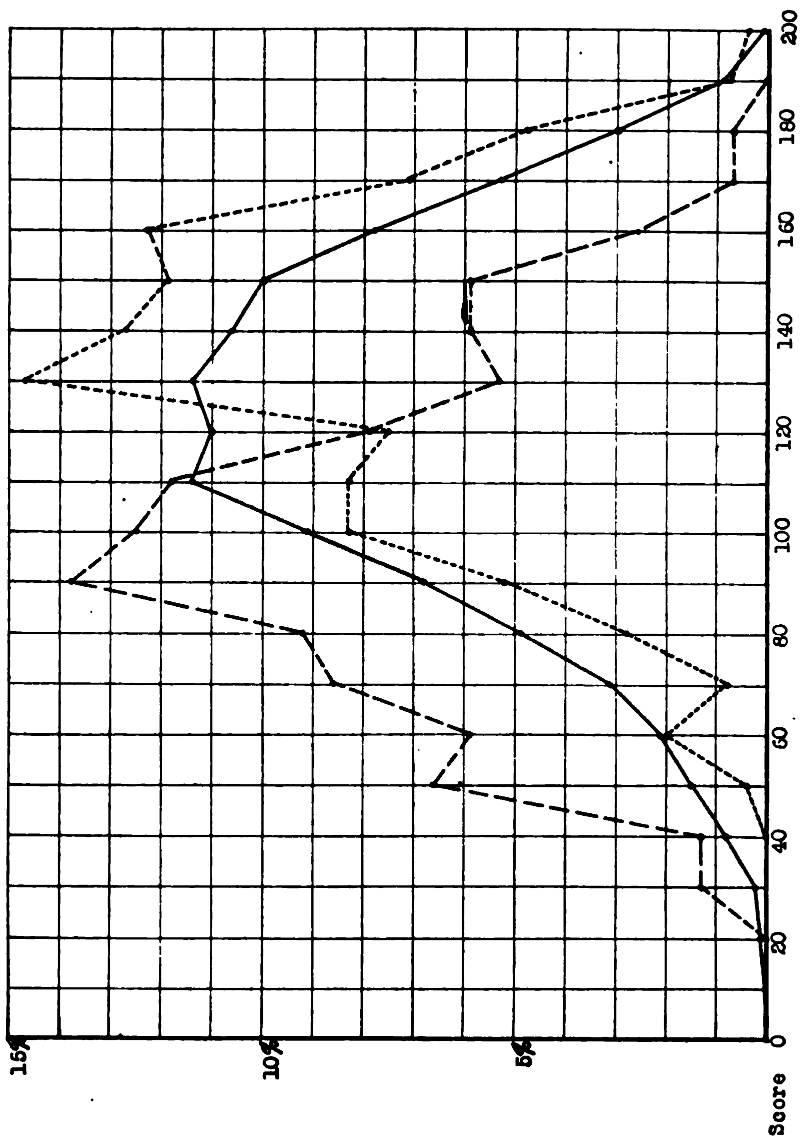

Fig. 6. Intelligence of medical officers in relation to geographical location. All medical officers (total of table 18), ——; South, — — —; Northeast, - - - - -

Population and intelligence.—In order to study relation of other facts to population of the community in which medical officers had practiced, communities with population of less than 2500 are classified as rural; 2500 to 249,999 as urban; 250,000 or more as metropolitan. For these three types of community the distribution of intelligence scores is given in table 19. There is a tendency for

TABLE 18

Distribution of alpha scores of doctors practicing in different parts of the country

Alpha score	North-east	Atlantic	South central	South	North central	Central	Western	Total
200–204	2	..	..	..	..	..	1	3
190–199	7	6	..	..	4	4	2	23
180–189	24	10	1	3	12	14	12	76
170–179	43	15	1	7	27	20	18	131
160–169	50	25	4	16	30	42	31	198
150–159	48	34	9	18	51	60	30	250
140–149	59	27	9	22	48	71	32	268
130–139	61	35	8	24	60	65	37	290
120–129	48	44	12	27	34	93	19	277
110–119	57	44	18	35	48	62	21	285
100–109	33	35	19	34	32	54	21	228
90–99	15	27	21	23	22	53	13	174
80–89	18	10	14	22	21	29	7	121
70–79	11	7	13	16	8	20	2	77
60–69	5	5	9	8	5	16	5	53
50–59	3	8	10	7	2	6	1	37
40–49	1	2	2	6	2	6	..	19
30–39	..	..	2	5	..	1	..	8
20–29	..	1	..	1	..	..	..	2
15–19	..	..	..	..	1	..	..	1
Total....	485	335	152	274	407	616	252	2521
Median..	138.8	126.1	102.3	115.2	135.1	126.0	140.0	129.2

the more intelligent medical men to practice in the larger communities. Although the differences in median scores are not great, they undoubtedly indicate that the less intelligent physician can more readily gain a practice in the less populous community.

Earnings of Medical Officers

Medical officers report annual earnings over a wide range. The highest amount reported is $75,000. The lowest, except for internes or those beginning practice, is $500. The distribution of earnings for the 1536 medical officers who reported this item is given in table 20, which indicates also median earnings of $4,318.40. Certain of the important factors influencing professional earnings are briefly considered below.

Earnings and location.—The earnings of the medical profession

TABLE 19

Distribution of alpha scores of doctors practicing in rural, urban and metropolitan communities

Alpha score	Rural under 2500	Urban 2500 to 249,999	Metropolitan[1] 250,000 and over	Total
205–212	.....	....	....	....
200–204	0.15	0.2	....	0.1
190–199	0.75	0.7	1.4	0.9
180–189	2.4	2.8	4.2	3.1
170–179	1.95	5.2	8.0	5.1
160–169	6.0	8.1	9.6	8.0
150–159	9.15	10.2	10.6	10.0
140–149	9.6	11.1	10.7	10.6
130–139	10.5	10.8	13.3	11.4
120–129	12.6	10.7	9.8	11.0
110–119	11.25	11.9	10.2	11.3
100–109	9.3	9.2	8.7	9.1
90–99	8.55	6.4	6.2	6.9
80–89	6.45	5.4	2.6	4.9
70–79	4.35	3.0	1.7	3.1
60–69	3.0	2.0	1.7	2.2
50–59	2.25	1.3	0.8	1.4
40–49	0.75	0.8	0.2	0.6
30–39	0.9	....	0.1	0.2
20–29	.....	0.1	0.1	0.1
10–19	.....	0.1	....	....
Total.........	666	1071	723	2460
Median.......	122.6	129	136.3	129.3

differ for sections of the country as shown by tables 21 and 22. These differences are similar to those for intelligence, despite the fact that the more intelligent officers do not earn most.

Earnings and population.—Tables 23 and 24 contain significant data on the relation of earnings to population of the community. The coefficient of correlation is +0.19. This figure is many times greater than its probable error and may be taken to indicate that density of population has a definite and positive relation to a physician's earnings.

Earnings and intelligence.—Surprising as it may appear, earnings

[1] Includes the following cities: Baltimore, Boston, Brooklyn, Buffalo, Chicago, Cincinnati, Cleveland, Denver, Detroit, Indianapolis, Kansas City, Los Angeles, Milwaukee, Minneapolis, New Orleans, New York, Newark, N. J., Philadelphia, Pittsburgh, Portland, Ore., Rochester, St. Louis, San Francisco, Seattle.

TABLE 20

Distribution of earnings of 1536 medical officers

Annual earnings	Number of cases	Percentage
$30,000 and over	8	0.5
25,000	4	0.3
20,000	9	0.6
18,000	7	0.5
16,000	5	0.3
14,000	22	1.4
12,000	36	2.3
10,000	75	4.9
9,000	30	2.0
8,000	64	4.2
7,000	59	3.8
6,000	142	9.2
5,000	170	11.1
4,000	201	13.1
3,000	297	19.3
2,500	119	7.7
2,000	155	10.1
1,500	66	4.3
1,000	49	3.2
500–999	18	1.2
Total[1]...........	1536	....
Median..........	$4,318.40	....

TABLE 21

Median annual earnings of doctors from different sections of the country

Section	Residence		Certificate		College	
	No. cases	Median earnings	No. cases	Median earnings	No. cases	Median earnings
Northeast....	274	$4781	274	$4742	457	$4667
Atlantic......	206	4774	204	4834	465	4930
South central	105	3184	121	3239	277	3525
Southern.....	185	3803	169	3838	154	3367
North central	249	4411	239	4339	339	4310
Central.......	355	4226	385	4385	746	4675
Western......	160	5000	113	4967	69	4214
Total......	1534	$4332	1505	$4338	1536	$4318

[1] Earnings were not given by 971 (38.8%) of the 2507 medical officers.

TABLE 22

Distribution of earnings of doctors practicing in different parts of the country

Annual earnings	Northeast	Atlantic	South central	Southern	North central	Central	Western	Totals
$30,000 and over	1	..	..	..	3	1	2	7
25,000	2	..	..	..	..	1	1	4
20,000	1	1	..	..	2	2	3	9
18,000	1	..	..	..	3	1	2	7
16,000	1	..	..	..	3	1	..	5
14,000	6	7	..	1	3	2	3	22
12,000	11	5	..	2	6	6	6	36
10,000	16	11	3	4	11	16	14	75
9,000	7	5	1	2	4	6	6	31
8,000	11	9	..	5	13	20	6	64
7,000	6	13	2	6	9	19	5	60
6,000	32	15	2	16	26	30	21	142
5,000	35	30	9	19	25	40	11	169
4,000	32	31	20	30	28	42	22	205
3,000	43	34	19	38	58	83	23	298
2,500	23	18	16	14	18	15	10	114
2,000	19	17	23	26	15	43	14	157
1,500	10	5	4	16	8	16	7	66
1,000	14	5	6	4	11	4	4	48
500–999	3	..	..	2	3	7	..	15
Total....	274	206	105	185	249	355	160	1534
Median earnings	$4781	$4774	$3184	$3803	$4411	$4226	$5000	$4337
Median experience	11.21	11.20	7.26	12.79	11.70	10.85	10.15	11.07

in the medical profession apparently are not dependent upon intelligence. The correlation between earnings and alpha scores (see table 25) is +0.06. On the possibility that this result might be misleading, the relationship was still further studied. It was thought that experience, because of its predominating influence, might obscure the importance of intelligence. The correlation was therefore computed for a closer experience-group of from 10 to 14 years. For this group earnings correlated with intelligence to the extent of +0.08. Since even this group had included an

TABLE 23

Differences in alpha score and in earnings between doctors practicing in rural, urban and metropolitan communities

Community	Alpha score		Earnings	
	No. cases	Median	No. cases	Median
Rural	666	122.6	448	$3606
Urban	1071	129.0	681	4994
Metropolitan[1]	723	136.3	378	4646
Total	2460	129.3	1507	$4380

TABLE 24

Correlation between earnings and size of town

Earnings	POPULATION								
	999	1,000	2,500	10,000	50,000	250,000	500,000	1,000,000	Total
$25,000 and over	..	..	..	2	4	2	..	3	11
18,000	..	..	2	4	3	4	1	2	16
14,000	..	1	2	9	7	4	3	1	27
12,000	2	1	3	10	7	4	2	7	36
10,000	5	4	13	18	9	7	7	12	75
8,000	4	9	19	18	16	8	12	8	94
6,000	17	28	36	38	39	19	12	12	201
4,000	67	45	66	54	49	37	25	28	371
3,000	69	35	29	57	34	29	19	22	294
2,500	22	16	13	12	17	16	5	7	108
2,000	53	25	17	14	16	10	9	8	152
1,500	20	2	9	8	7	3	2	8	59
1,000	14	5	3	8	3	5	5	5	48
500-999	4	..	3	2	1	3	1	1	15
Total	277	171	215	254	212	151	103	124	1507
$r = +0.19$									

extreme difference in experience of 5 years, further selection was made and the correlation between earnings and intelligence was computed for 88 medical officers who reported 12 years' experience. The result was +0.07. These correlations are too low to be significant practically, if not statistically.

[1] For list of cities included see table 19.

Earnings, experience and military rank.—The physician's earning capacity, according to the statistical data for the group of medical officers, is closely related to the length of his practical experience. This appears from the medians of table 26. There is a steady increase in median earnings up to 20 years' experience and there-

TABLE 25

Correlation between earnings and alpha score

Alpha score	Earnings														Total
	$500–999	1,000	1,500	2,000	2,500	3,000	4,000	6,000	8,000	10,000	12,000	14,000	18,000	25,000 and over	
200–212	..	..	..	..	..	..	2	..	..	..	..	..	..	..	2
190–199	..	..	..	3	1	3	6	1	..	..	..	..	..	..	14
180–189	..	..	3	3	1	9	12	9	2	4	1	2	1	1	48
170–179	1	5	..	4	8	13	20	9	2	1	2	3	1	..	69
160–169	..	4	3	10	6	23	23	18	4	7	4	4	1	1	108
150–159	1	6	10	12	14	30	37	30	7	6	2	2	3	2	162
140–149	1	4	5	21	10	28	26	23	11	7	3	1	1	3	144
130–139	2	6	7	14	13	37	40	20	10	7	3	5	2	1	167
120–129	..	3	7	14	6	36	41	24	15	9	4	2	1	1	163
110–119	3	4	7	15	17	31	43	23	9	8	5	3	1	..	169
100–109	1	5	9	14	11	34	36	12	13	8	2	4	2	1	152
90–99	1	5	5	12	7	16	27	13	11	4	2	..	1	1	105
80–89	2	1	1	15	8	12	21	6	4	5	4	1	..	..	80
70–79	..	2	5	10	4	6	15	3	3	4	2	..	1	..	55
60–69	..	2	..	5	3	4	11	6	2	4	1	..	1	..	39
50–59	1	..	2	3	3	6	8	4	1	1	1	..	..	..	30
40–49	1	..	1	1	1	5	5	1	1	..	..	..	..	..	16
30–39	..	1	..	..	1	4	..	..	..	..	..	..	..	..	6
20–29	..	..	..	1	..	..	..	..	..	..	..	..	..	..	1
10–19	1	..	..	..	..	..	..	..	..	..	..	..	..	..	1
Total...	15	48	65	157	114	297	373	202	95	75	36	27	16	11	1531
$r = +0.06$															

after a decrease, according to the data of this table. This result may be due to selectional processes operating in the Medical Department, for ordinarily physicians with more than 25 years' experience would not be accepted for service.

The correlation between earnings and experience as computed from table 27 is +0.25. This is not a high correlation but it indicates the closest relationship which has been found between earnings and any other variable.

TABLE 26

Median earnings of groups reporting different length of experience

Years' experience	No. cases	Median earnings
1–3	147	$2529
4–6	206	3686
7–9	232	4594
10–14	394	4914
15–19	277	4956
20–24	177	4938
25 and over	98	4625
Total..........	1531	$4339

Earnings are importantly related to the military rank an officer received, as appears from table 28. Or differently viewed, the rank of medical officers varies directly with experience, as does also their annual earning capacity in civil practice.

TABLE 27

Correlation between earnings and experience

Earnings	Years of experience							Total
	1–3	4–6	7–9	10–14	15–19	20–24	25 and above	
$25,000 and over	..	..	2	3	1	2	3	11
18,000	..	1	2	4	2	4	3	16
14,000	..	..	3	8	9	7	..	27
12,000	..	1	5	14	8	6	2	36
10 000	2	10	10	22	15	9	7	75
8,000	1	10	14	28	21	9	11	94
6,000	3	23	39	63	35	32	7	202
4,000	14	42	60	108	82	42	26	374
3,000	29	51	46	69	49	35	18	297
2,500	26	18	11	21	23	12	3	114
2,000	29	26	24	34	24	13	7	157
1,500	17	17	7	12	3	4	5	65
1,000	19	5	7	6	5	1	5	48
500–999	7	2	2	2	..	1	1	15
Total.....	147	206	232	394	277	177	98	1531
$r = +0.25$								

Earnings and specialty.—Another factor which has definite relationship to the annual earnings of the medical officer is his specialty. It has been found, for instance, that those reporting themselves as surgeons earn $5,666, whereas those listed as specialists in mental and nervous diseases report earnings of $3,312. These facts appear in table 29 along with data for certain other

TABLE 28

Earnings and military rank

Earnings	Lieutenants	Captains	Majors and above	Total
$30,000 and over	...	5	3	8
25,000	2	1	1	4
20,000	2	5	2	9
18,000	...	6	1	7
16,000	1	4	..	5
14,000	6	11	5	22
12,000	14	18	4	36
10,000	32	37	6	75
9,000	9	19	2	30
8,000	27	34	2	63
7,000	28	28	3	59
6,000	76	61	6	143
5,000	92	72	6	170
4,000	121	65	15	201
3,000	199	86	10	295
2,500	90	28	2	120
2,000	120	35	1	156
1,500	54	10	2	66
1,000	40	9	..	49
500–999	15	3	..	18
Not given..........	573	326	72	971
Total..............	1501	863	143	2507
Median............	$3728	$5451	$5916	$4318
Median, years' experience.........	7.71	15.76	17.67	11.07

important special groups. For ready comparison the median alpha scores also are inserted. Internal medicine provides next to the highest intelligence score, 142.5 points, whereas surgery with a median score of 126.8 points reports larger earnings. This is probably due on the one hand to the inclusion in the surgical group of a number of practitioners whose earnings are exceptionally

large, and on the other hand to the fact that the Medical Department undoubtedly utilized the services of a considerable number of surgeons of low grade intelligence.

To sum up this account of the relations of earnings, it would seem that length of experience, field of specialization, population of the community and geographical location are importantly related to earning capacity. On the other hand, earning capacity appears

TABLE 29

Earnings and intelligence of specialists in different fields

Specialty	Earnings		Alpha scores	
	No. cases	Median	No. cases	Median
Surgery	395	$5666	571	126.8
Internal medicine	102	5481	159	142.5
Eye, ear, nose and throat	139	5182	205	128.3
Gynecology and obstetrics	61	4622	78	127.5
Genito-urinary, urology	49	3812	69	131.5
General practice	463	3782	999	125.2
Roentgenology, X-ray, Radiography	35	3750	45	132.5
Not given	143	3342	...	.....
Mental and nervous	35	3312	50	143.0
Total	1536	$4318	2507	129.2

to be practically independent of intelligence as measured by army examination alpha.

Military Relations and Specialty of Medical Officers

Military appointment and intelligence.—Several interesting aspects of the relation of doctors to the military machine may be seen through these data. By far the larger part of the group had been commissioned in the Medical Officers Reserve Corps. There were included, however, a small group of officers of the National Guard and another of the Regular Army. These two small groups made a much better showing on examination alpha than did the larger group from the Medical Officers Reserve Corps. The medical officers of the Regular Army, in fact, did as well as officers of any branch of the army except the engineers. The small size of the group, however, makes the reliability of the median un-

certain. The median score is 143 for the National Guard and Regular Army combined, as compared with 128.6 for the Medical Reserve Corps.

Military assignment, specialty and promotion.—The specialties reported by our group of medical officers appear in table 30. There was, of course, some attempt to recognize civilian specialization in military assignment. The available data concerning civilian specialization and assignment to special work in the Medical Department have been assembled in table 31, which shows the number of cases in which assignment was to the specialist's own field, the number in which it was different, and the number in which no record appears.

TABLE 30

Specialties reported

Specialty	No. of cases	Percentage
Anesthesia	37	1.6
Eye	46	2.0
Eye, ear, nose and throat	193	8.5
Genito-urinary	77	3.4
Gynecology and obstetrics	88	3.9
Internal medicine	178	7.8
Mental and nervous diseases	54	2.4
Roentgenology	52	2.3
Surgery	640	28.2
General practice	683	30.0
Miscellaneous	224	9.9
Total, specialty given[1]	2272	....

Similarly table 32 shows the number and percentage of promotions on record for each division of the Medical Department and for each specialty. Promotions were more frequent in some divisions than in others. They do not appear, however, to have been more frequent for medical officers who were assigned to their own specialty than for others. The high frequency of promotion in the group whose assignment is unknown is unexplained.

Military rank and its relations.—The rank of the medical officer, and especially the rank to which he was commissioned from ci-

[1] Of the 2507 medical officers, 235 failed to indicate either specialty or general practice.

TABLE 31

Relation of military assignment to specialty in civil life

Specialty	Military assignment: Laboratory division	Permanent staff	Sanitation	Eye, ear, nose and throat	Genito-urinary diseases	Internal medicine	Mental and nervous diseases	Orthopedics	Roentgenology	Surgery	Tuberculosis	Venereal diseases	General service	Field service	Reconstruction, Division of Hospitals, and Aviation	Assignment same	Percentage	Assignment different	Percentage	Total, assignment known	Assignment not known	Total
Anesthesia	..	..	..	1	..	1	..	..	..	9	..	..	14	5	1	0	0	31	100	31	4	35
Gynecology and obstetrics	..	..	1	..	..	6	..	2	1	25	..	1	15	11	1	0	0	63	100	63	24	87
Eye	..	..	..	20	..	2	..	..	..	...	..	..	7	4	1	20	59	14	41	34	12	46
Eye, ear, nose and throat	..	1	4	114	..	2	..	1	..	1	1	..	26	13	2	114	69	51	31	165	29	194
Genito-urinary diseases	2	..	..	...	40	2	..	..	..	4	..	1	5	3	...	40	70	17	30	57	20	77
Internal medicine	1	3	2	1	..	98	..	1	1	2	4	..	18	7	...	98	71	40	29	138	41	179
Mental and nervous diseases	..	..	4	...	1	1	19	..	..	...	..	..	2	2	1	19	63	11	37	30	24	54
Orthopedics	..	..	..	...	..	...	..	13	..	...	..	..	1	1	...	13	87	2	13	15	1	16
Roentgenology	..	1	..	...	..	...	..	..	30	5	..	..	...	2	1	30	68	15	32	45	9	54
Surgery	..	4	8	...	5	25	..	20	6	285	..	..	95	42	4	285	58	209	42	494	146	640
Tuberculosis	..	1	..	...	..	5	..	..	..	...	9	..	5	2	2	9	37.5	15	62.5	24	10	34
Venereal diseases	1	..	..	...	1	...	..	..	..	...	..	3	3	2	1	3	27	8	73	11	1	12
General practice	2	2	20	3	2	71	1	4	4	57	3	..	74	96	11	270	60	180	40	450	233	683
Miscellaneous	24	6	3	0	0	40	..	1	1	3	1	..	22	6	4	17	15	94	85	111	52	163
Not known	6	3	6	5	2	8	1	6	..	24	..	..	5	18	2	...	....	86	.....	86	147	233
Total	36	21	48	144	51	261	21	48	43	415	18	5	398	214	31	918	52	836	48	1754	753	2507
Specialty different from assignment: No.	15	14	46	10	11	163	2	35	13	130	9	2	224	118	31							
Specialty different from assignment: %	42	67	96	7	22	62	10	73	30	31	50	40	56	55	100							

TABLE 32

Relation of promotion in the army to assignment and specialty (percentages)

Specialty	Military assignment: Laboratory division	Permanent staff	Sanitation	Eye, ear, nose and throat	Genito-urinary diseases	Internal medicine	Mental and nervous diseases	Orthopedics	Roentgenology	Surgery	Tuberculosis	Venereal diseases	General service	Field service	Reconstruction, Division of Hospitals and Aviation	Assignment same	Assignment different	Assignment not known	Percentage of total promoted	Number of promotions
Anesthesia	...	...	...	0	..	0	..	..	...	0	...	...	0	0	0	...	0	75	9	3
Gynecology and obstetrics	...	...	0	...	..	0	..	0	100	12	...	0	7	0	0	...	8	21	12	10
Eye	...	...	...	10	..	0	..	..	...	..	...	...	0	0	100	10	7	42	17	8
Eye, ear, nose and throat	...	0	25	19	..	0	..	0	...	0	0	...	0	0	100	19	6	45	20	38
Genito-urinary diseases	0	...	...	...	13	0	..	..	...	0	...	100	0	0	...	13	6	45	19	15
Internal medicine	100	67	100	100	..	15	..	0	...	0	50	...	0	0	...	15	20	56	26	46
Mental and nervous diseases	...	...	25	...	0	0	21	..	...	..	...	...	0	0	0	21	9	50	31	17
Orthopedics	...	...	...	...	..	..	..	23	...	..	...	...	0	0	...	23	0	100	25	14
Roentgenology	...	100	...	...	..	..	..	..	17	20	...	...	0	0	0	17	13	33	19	10
Surgery	...	75	38	...	0	36	..	20	17	13	...	...	0	7	0	13	11	45	20	125
Tuberculosis	...	100	...	...	..	40	..	..	...	..	11	...	0	0	100	11	33	40	29	10
Venereal diseases	0	...	...	...	0	..	..	..	...	..	...	0	0	0	...	0	0	0	0	0
General practice	0	100	35	33	0	15	0	0	0	12	100	...	0.6	1	31	0.6	19	52	23	157
Miscellaneous	17	33	33	...	..	13	..	0	0	33	0	...	0	0	50	18	13	46	24	39
Not known	33	0	50	40	50	25	0	0	0	46	...	...	0	0	50	...	...	39	34	80
Percentage of total, promoted	19	52	38	19	12	17	19	15	16	14	33	20	0.5	2	39	11	14	46	22	...
Number of promotions	7	11	18	28	6	44	4	7	7	60	6	1	2	4	12	99	118	345	...	562

vilian life, depended primarily on age, length of experience and earnings in civil life.

Table 33 presents the median values by rank of medical officers, for intelligence, experience, schooling and earnings.

TABLE 33

Rank of medical officers and intelligence, experience, schooling and earnings

Median values	Lieutenant	Captain	Major and above	All medical officers
Intelligence........	128	134	149	129.2
Experience.........	7.71	15.76	17.67	11.07
Schooling..........	15.80	15.80	15.73	15.8
Earnings...........	$3728	$5451	$5916	$4318

TABLE 34

Distribution of alpha scores of medical officers of different ranks

Alpha score	Lieutenant	Captain	Major and above	Total
200–204	1	2	..	3
190–199	12	7	3	22
180–189	34	32	11	77
170–179	72	46	13	131
160–169	114	62	19	195
150–159	146	86	19	251
140–149	151	94	21	266
130–139	170	98	19	287
120–129	165	100	11	276
110–119	184	91	10	285
100–109	144	75	7	226
90–99	113	53	7	173
80–89	73	46	1	120
70–79	45	30	1	76
60–69	33	19	1	53
50–59	24	13	..	37
40–49	13	6	..	19
30–39	6	1	..	7
20–29	1	1	..	2
15–19	..	1	..	1
Total........	1501	863	143	2507
Median......	128	134	149	129.2

Membership of Medical Officers in Medical Societies

In the group of officers studied, 1964 individuals reported membership in medical societies of the United States. The number of societies reported ranges from 1 to 7. Over 25% of those reporting held membership in three medical societies. Over 50% report membership in one or two societies. Membership in no medical society was reported by 237 officers. Of the 1964 officers reporting membership in medical societies, 50.7% were members of the American Medical Association. The median intelligence score of those reporting themselves as members of the American Medical Association is 128.2; that of non-members, 129.8.

DATA CONCERNING MEDICAL SCHOOLS

Over 130 medical schools are represented by this group of 2507 medical officers. The number of men from a single school was, in most cases, small, the largest number being 118 from Rush Medical College. Only 18 schools were represented by as many as 35 individuals. Statistics for these 18 schools are given later. In general, it was necessary, if reliable figures were to be obtained, to consider schools by groups. They were grouped first according to location. The geographical groups thus obtained yielded information which confirms geographical data already presented. The schools were next grouped by size. Certain statements may be made concerning the large schools as compared with those which have few students. They were then grouped according to entrance requirements. Groupings were also made according to the rating of the school by the American Medical Association, and according to the medical sect followed. The groupings obtained on these different bases have been compared as to score in intelligence examination alpha, income reported and length of experience.

Geographical Classification

The geographical grouping of states is that previously used for grouping medical officers (table 16).

Geographical Grouping of Medical Schools

NORTHEAST:

University and Bellevue Hospital Medical College.
Boston University School of Medicine.
Bowdoin Medical School.
University of Buffalo Department of Medicine.
College of Physicians and Surgeons, Boston.

Columbia University College of Physicians and Surgeons.
Cornell University Medical College.
Dartmouth Medical School.
Fordham University School of Medicine.
Medical School of Harvard University.
Long Island College Hospital.
New York Homeopathic Medical College and Flower Hospital.
Eclectic Medical College of the City of New York.
Syracuse University, College of Medicine.
Tufts College Medical School.
Union University.
University of Vermont College of Medicine.
Yale University School of Medicine.

ATLANTIC:
Baltimore University School of Medicine.
Hahnemann Medical College and Hospital of Philadelphia.
Jefferson Medical College of Philadelphia.
Johns Hopkins University Medical Department.
Maryland Medical College.
University of Maryland School of Medicine and the College of Physicians and Surgeons.
Medico-Chirurgical College of Philadelphia.
University of Pennsylvania School of Medicine.
University of Pittsburgh School of Medicine.
Temple University Department of Medicine.
Medical College of Virginia.
University of Virginia Department of Medicine.

SOUTH CENTRAL:
University of Chattanooga Medical Department.
University of Louisville Medical Department.
University of Nashville Medical Department.
North Carolina Medical College.
Medical College of the State of South Carolina.
University of the South Medical College.
Southwestern Homeopathic Medical College and Hospital.
University of Tennessee College of Medicine.
Vanderbilt University Medical Department.

SOUTHERN:
University of Alabama School of Medicine.
University of Arkansas Medical Department.
Hospital Medical College, Eclectic, Atlanta.
Baylor University College of Medicine.
Emory University School of Medicine.
Georgia College of Eclectic Medicine and Surgery.
University of Georgia Medical Department.
Mississippi Medical College.
University of Oklahoma School of Medicine.
Physio-Medical College of Texas.
Southern Methodist University Medical Department.

Medical Department of the Texas Christian University.
University of Texas Department of Medicine.
Tulane University of Louisiana School of Medicine.

NORTH CENTRAL:
Cincinnati College of Medicine and Surgery.
Eclectic Medical College, Cincinnati.
University of Cincinnati College of Medicine.
Cleveland Homeopathic Medical College.
Detroit Homeopathic Medical College.
Detroit Medical College.
Grand Rapids Medical College.
Medical Department Hamline University.
Marquette University School of Medicine.
University of Michigan Medical School.
University of Michigan Homeopathic Medical School.
Milwaukee Medical College.
Minneapolis College of Physicians and Surgeons.
University of Minnesota Medical School.
University of Minnesota College of Homeopathic Medicine and Surgery.
Ohio State University, College of Medicine.
Saginaw Valley Medical College.
Toledo Medical College.
Western Reserve University School of Medicine.
Wisconsin College of Physicians and Surgeons.

CENTRAL:
Chicago College of Medicine and Surgery.
Dearborn Medical College.
Ensworth Medical College.
Hahnemann Medical College and Hospital of Chicago.
Hering Medical College.
University of Illinois College of Medicine.
Indiana Eclectic Medical College.
Indiana University School of Medicine.
Physio-Medical College of Indiana.
State University of Iowa College of Medicine.
State University of Iowa College of Homeopathic Medicine.
Jenner Medical College.
John A. Creighton Medical College.
University of Kansas School of Medicine.
University Medical College of Kansas City.
Eclectic Medical University, Kansas City.
Lincoln Medical College.
Chicago College of Medicine and Surgery, School of Medicine of Loyola University.
Homeopathic Medical College of Missouri.
National Medical University, Chicago.
National University of Arts and Sciences, St. Louis.
University of Nebraska College of Medicine.
Northwestern University Medical School.
Rush Medical College.
Sioux City College of Medicine.

Kansas City Hahnemann Medical College.
St. Louis University School of Medicine.
Washington University Medical School.

WESTERN:

University of California Medical School.
Hahnemann Medical College of the Pacific.
University of Southern California (College of Physicians and Surgeons).
University of Southern California Medical College.
California Eclectic Medical College.
University of Colorado School of Medicine.
Leland Stanford Junior University School of Medicine.
University of Oregon Medical School.
College of Physicians and Surgeons of San Francisco.

Distribution of alpha scores of men who were graduated from schools in each section is similar to that shown in table 17. This is naturally the case, as the groups of men from schools in different sections overlap to a large extent the group of doctors practicing in these sections so that many members of the group are identical. In other words, the majority of the doctors attended school in the same state in which they are practicing; they usually hold certificate from that state, or from the state in which their school is situated. It is interesting to find that on the whole the schools, good or poor, large or small, of a given section of country, did represent fairly well the intelligence level of the medical profession in that section.

Difference in the earning power of graduates from schools of these groups are again so closely similar to the difference shown in table 22 that they need not be again presented. The South central group of states is again the lowest in the median pay received by doctors graduated from schools within its borders. The differences are somewhat smaller than those of table 22 and are doubtless partially due to the fact that graduates of these schools are also largely practicing in these states.

Classification of the Medical Schools by Size

When graded according to size the schools represented fall into the classification which follows. (The figures were taken from the American Medical Directory for 1918, which gives the number of students registered in 1916–17.)

Grouping of Schools by Size

0–49 students

University of Alabama School of Medicine, Mobile.
University of Arkansas Medical Department, Little Rock.

Dartmouth Medical School, Hanover, N. H.
State University of Iowa College of Homeopathic Medicine, Iowa City.
Lincoln Medical College, Eclectic, Lincoln, Nebraska.
Eclectic Medical University, Kansas City, Missouri.
University of Michigan Homeopathic Medical School, Ann Arbor.

50–99 students

Baylor University College of Medicine, Dallas, Texas.
Boston University School of Medicine, Boston, Mass.
Bowdoin Medical School, Medical Department of Bowdoin College, Brunswick and Portland, Maine.
Eclectic Medical College, Cincinnati, Ohio.
College of Physicians and Surgeons, Boston, Mass.
University of Colorado School of Medicine, Boulder and Denver.
Georgetown University School of Medicine, Washington, D. C.
University of Georgia Medical Department, Augusta.
Hahnemann Medical College and Hospital of Chicago, Ill.
University of Oklahoma School of Medicine, Norman and Oklahoma City.
College of Physicians and Surgeons of San Francisco, Calif.
Medical College of the State of South Carolina, Charleston.
Temple University Department of Medicine, Philadelphia, Pa.
Medical Department of the Texas Christian University, Fort Worth.
University of Vermont College of Medicine, Burlington.
Yale University School of Medicine, New Haven, Conn.

100–149 students

University of California Medical School, Berkeley and San Francisco.
University of Southern California College of Medicine, Los Angeles.
Hahnemann Medical College of the Pacific, San Francisco, California.
College of Physicians and Surgeons (Medical Department of the University of Southern California), Los Angeles.
Leland Stanford Junior University School of Medicine, Palo Alto and San Francisco, California.
University of Kansas School of Medicine, Lawrence and Rosedale.
Kansas Medical College, Topeka.
John A. Creighton Medical College, Medical Department of the Creighton University, Omaha, Nebraska.
Jenner Medical College, Chicago, Ill.
Hahnemann Medical College and Hospital of Philadelphia, Pa.
George Washington University Medical School (National University Medical Department), Washington, D. C.
University of Louisville Medical Department, Louisville, Ky. (Hospital College of Medicine, Medical Department, Central University of Kentucky; Kentucky School of Medicine; Kentucky University Medical Department; and Louisville Medical College).
University of Nebraska College of Medicine, Omaha, Neb.
University of Pittsburgh School of Medicine, Pittsburgh, Pa.
Syracuse University College of Medicine, Syracuse, N. Y.
Union University Medical Department (Albany Medical College), Albany, N. Y.
University of Virginia Department of Medicine, Charlottesville.
Washington University Medical School, St. Louis, Missouri.
St. Louis Medical College, St. Louis, Missouri.
Missouri Medical College, St. Louis, Missouri.

150–199 students

University of Buffalo Department of Medicine, Buffalo, N. Y.
Cornell University Medical College, Ithaca and New York City, N. Y.
Detroit College of Medicine and Surgery, Detroit, Mich.
Indiana University School of Medicine, Bloomington and Indianapolis.
Medico-Chirurgical College of Philadelphia, Pa.
New York Homeopathic Medical College and Flower Hospital, New York City.
Vanderbilt University Medical Department, Nashville, Tenn.

200–249 students

University of Illinois College of Medicine, Chicago.
Northwestern University Medical School, Chicago.

250–299 students

St. Louis University School of Medicine, St. Louis, Mo.
Fordham University School of Medicine, New York City.
Long Island College Hospital, Brooklyn, N. Y.
University of Minnesota Medical School, Minneapolis.
University of Texas Department of Medicine, Galveston.
Tulane University of Louisiana School of Medicine, New Orleans.

300–399 students

Medical School of Harvard University, Boston, Mass.
Johns Hopkins University Medical Department, Baltimore, Md.
University of Michigan Medical School, Ann Arbor.
Tufts College Medical School, Boston, Mass.

400 or more students

University and Bellevue Hospital Medical College, New York City.
Columbia University College of Physicians and Surgeons, New York City.
Jefferson Medical College of Philadelphia, Pa.
University of Pennsylvania School of Medicine, Philadelphia.
Rush Medical College, Chicago, Ill.

Unclassified

University of Cincinnati College of Medicine, Cincinnati, Ohio.
Emory University School of Medicine, Atlanta, Georgia.
Chicago College of Medicine and Surgery, School of Medicine of Loyola University, Chicago, Ill.
State University of Iowa, College of Medicine, Iowa City.
Marquette University School of Medicine, Milwaukee, Wis.
University of Maryland School of Medicine and the College of Physicians and Surgeons, Baltimore, Md.
Ohio State University College of Medicine, Columbus.
University of Oregon Medical School, Portland.
University of Tennessee College of Medicine, Memphis.
Medical College of Virginia, Richmond.
Western Reserve University School of Medicine, Cleveland, Ohio.

Extinct

Hospital Medical College, Eclectic, Atlanta, Georgia.

Atlantic Medical College, Baltimore, Md.
Baltimore University School of Medicine, Baltimore, Md.
California Eclectic Medical College, Los Angeles, Calif.
Chattanooga Medical College, Chattanooga, Tenn.
Cincinnati College of Medicine and Surgery, Cincinnati, Ohio.
Cleveland Homeopathic Medical College, Cleveland, Ohio.
Dearborn Medical College, Chicago, Ill.
Detroit Homeopathic Medical College, Detroit, Mich.
Ensworth Medical College, St. Joseph, Mo.
Georgia College of Eclectic Medicine and Surgery, Atlanta.
Grand Rapids Medical College, Grand Rapids, Mich.
Hering Medical College, Chicago, Ill.
Indiana Eclectic Medical College, Indianapolis.
Physio-Medical College of Indiana, Indianapolis.
University Medical College of Kansas City, Mo.
Maryland Medical College, Baltimore.
Milwaukee Medical College, Milwaukee, Wis.
University of Minnesota College of Homeopathic Medicine and Surgery, Minneapolis.
Homeopathic Medical College of Missouri, St. Louis.
Mississippi Medical College, Meridian.
University of Nashville Medical Department, Nashville, Tenn.
National Medical University, Chicago, Ill.
National University of Arts and Sciences, Medical Department, St. Louis, Mo.
Eclectic Medical College of the City of New York.
Saginaw Valley Medical College, Saginaw, Mich.
Sioux City College of Medicine, Sioux City, Iowa.
University of the South Medical College (Sewanee Medical College), Sewanee, Tenn.
Southern Methodist University Medical Department, Dallas, Texas.
Kansas City Hahnemann Medical College, Kansas City, Mo.
Southwestern Homeopathic Medical College and Hospital, Louisville, Ky.
Toledo Medical College (Medical Department Toledo University), Toledo, Ohio.
Wisconsin College of Physicians and Surgeons, Milwaukee, Wis.

The first question is whether the men graduated from the larger institutions are a more intelligent group than those from the smaller schools. Table 35 shows that on the whole they are. Differences are not very large, and the variations are rather irregular. The lowest group of schools with less than 50 students is represented by only 59 individuals, too few for reliability. In figure 7 the three lowest groups, including all those from schools with less than 150 students, are compared with the groups from schools with 300 or more students each. This large-attendance group, including nine different schools, stands out as distinctly above the others in intelligence.

The earnings reported by graduates from schools of different size fall in a manner which is irregular and almost impossible to interpret. It seems obvious that other factors than the size of the

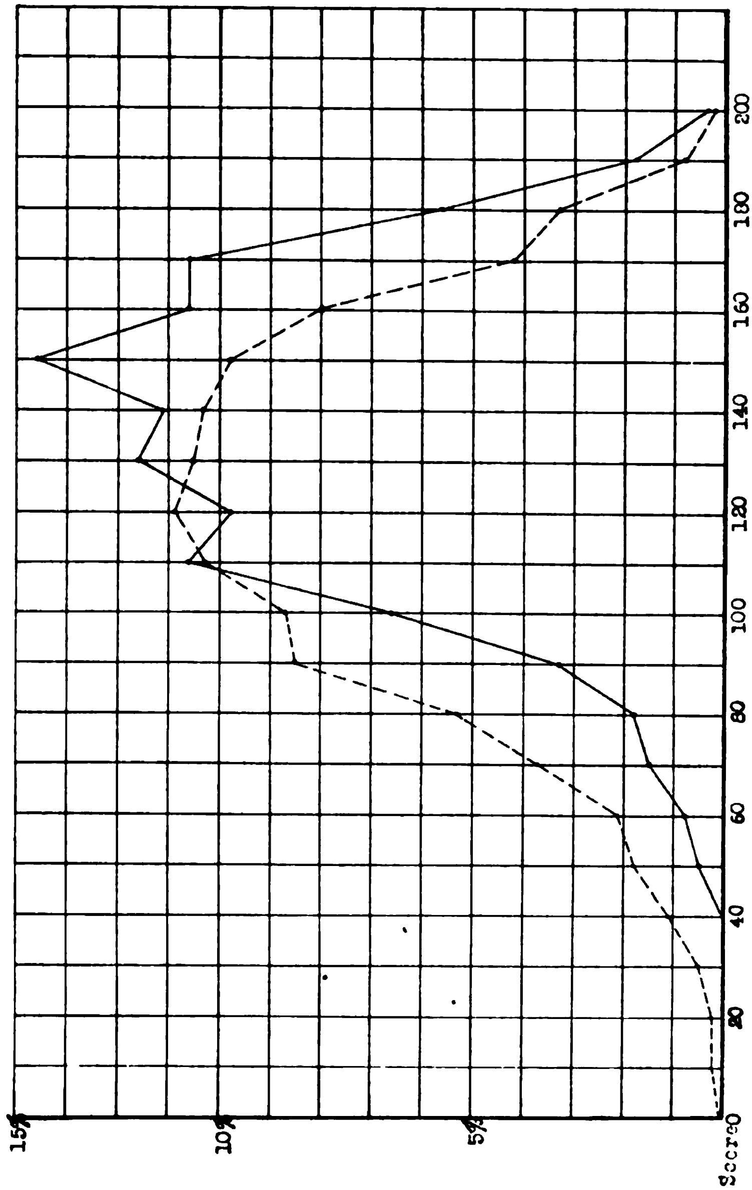

Fig. 7. Intelligence of graduates of large and small medical schools. Schools under 150 students, – – – –; schools with 300 or more students, ———.

school have an important influence on the type of student, so that the influence of size is obscured. Some of the groups contain so few schools that they are not representative geographically, and probably not in other ways. For instance, schools having from 200 to 249 students are represented only by the University of Illinois

TABLE 35

Distribution of alpha scores of graduates from schools of different size

Alpha score	Number of students								Extinct schools	Unclassified schools	Total
	0 to 49	50 to 99	100 to 149	150 to 199	200 to 249	250 to 299	300 to 399	400 or more			
200–204	1	..	..	..	..	..	1	1	..	..	3
190–199	1	1	3	1	..	2	3	8	1	2	22
180–189	1	8	10	4	5	3	13	21	2	10	77
170–179	3	11	12	9	7	7	22	42	4	14	131
160–169	6	16	28	11	19	15	25	39	13	23	195
150–159	5	16	40	22	16	15	19	63	13	41	250
140–149	4	19	41	23	34	17	27	40	20	41	266
130–139	4	21	40	22	23	27	25	45	21	61	289
120–129	9	14	45	27	26	16	19	40	19	61	276
110–119	6	20	38	30	17	23	17	47	22	64	284
100–109	4	9	41	22	17	17	14	26	16	60	226
90– 99	6	18	29	17	4	13	1	19	13	52	172
80– 89	5	6	22	15	6	9	3	8	16	31	121
70– 79	2	6	15	8	2	9	2	7	8	17	76
60– 69	.	3	10	3	3	1	1	4	8	20	53
50– 59	1	2	8	2	1	2	..	3	4	14	37
40– 49	1	..	6	1	..	1	..	..	2	8	19
30– 39	.	..	3	1	..	1	..	..	..	2	7
20– 29	.	..	1	..	..	..	..	..	1	..	2
10– 19	.	..	1	..	..	..	..	..	..	..	1
Total...	59	170	393	218	180	178	192	413	183	521	2507
Median	126.3	133.5	124.7	123.6	135.9	127	145.4	142.2	120.5	119.1	129.2

College of Medicine and Northwestern University Medical School, both in Chicago. The experience of the different groups is uneven and interferes with direct comparison. Table 36 indicates the distribution of earnings and median experience in the groups of schools of different size.

Classification of the Medical Schools by Entrance Requirements

As it was impracticable to ascertain the entrance requirement of each school for every year in which a member of the group of medical officers entered it, classification has been made on the basis of the entrance requirement guaranteed as enforced in the year 1916–1917. This information was contained in a personally certified letter to the Surgeon General of the Army from a responsible school official of each college. It is obvious that this method of

TABLE 36

Distribution of earnings of graduates from schools of different size

Annual earnings	Number of students: 0 to 49	50 to 99	100 to 149	150 to 199	200 to 249	250 to 299	300 to 399	400 and above	Extinct schools	Unclassified schools	Total
$30,000 and over	..	..	2	..	..	1	1	3	..	1	8
25,000	..	..	..	..	1	..	..	1	..	1	4
20,000	..	..	..	..	..	1	2	3	1	3	9
18,000	..	..	1	..	..	..	2	3	..	1	7
16,000	..	1	..	1	..	..	1	1	1	..	5
14,000	..	2	1	3	3	..	2	10	..	2	23
12,000	1	1	4	2	7	3	1	8	4	4	35
10,000	2	3	14	4	5	6	8	18	4	11	75
9,000	..	1	3	3	5	2	2	7	2	5	30
8,000	1	3	5	7	5	9	6	11	5	12	64
7,000	2	2	13	6	6	2	2	14	2	10	59
6,000	2	13	18	14	11	15	13	20	13	23	142
5,000	4	18	25	12	15	11	11	25	15	34	170
4,000	8	15	37	17	9	13	11	28	14	49	201
3,000	13	17	51	24	21	19	19	36	26	71	297
2,500	2	11	16	15	3	6	10	15	12	29	119
2,000	2	12	38	9	6	12	8	17	13	38	155
1,500	1	7	11	4	3	11	2	7	6	14	66
1,000	1	3	10	4	..	3	7	8	1	12	49
500–999	1	..	5	3	1	1	1	2	..	4	18
Earnings not known	19	61	139	90	79	63	83	176	64	197	971
Total...	59	170	393	218	180	178	192	413	183	521	2507
Median	$4000	$4233	$3922	$4294	$5500	$4423	$4682	$5240	$4107	$3915	$4318
Median score	126.3	133.5	124.7	123.6	135.9	127	145.4	142.2	120.5	119.1	129.2
Median years' experience	8.8	11.01	12.97	10.81	9.08	9.65	9.4	12.13	13.48	10.18	11.07

classification is unsatisfactory since many of the poorer schools have ceased to exist or have increased their entrance requirements, whereas better schools have made less radical changes.

The lowest requirement reported is one year of college work in addition to high school graduation and certain science requirements.

The highest requirement (the Johns Hopkins Medical School only) is graduation from college.

Grouping of Schools by Entrance Requirements

One year of college work

University of Arkansas Medical Department.
Baylor University College of Medicine.
University and Bellevue Hospital Medical College.
Eclectic Medical College, Cincinnati.
Detroit College of Medicine and Surgery.
Emory University School of Medicine.
Fordham University School of Medicine.
George Washington University Medical School.
University of Georgia Medical Department.
Hahnemann Medical College and Hospital of Philadelphia.
John A. Creighton Medical College.
University of Louisville Medical Department.
Chicago College of Medicine and Surgery, School of Medicine of Loyola University.
Long Island College Hospital.
University of Maryland School of Medicine and the College of Physicians and Surgeons.
New York Homeopathic Medical College and Flower Hospital.
University of Oregon Medical School, and Willamette University Medical Department.
St. Louis University School of Medicine.
Temple University Department of Medicine.
University of Tennessee College of Medicine.
Medical Department of the Texas Christian University.
Tulane University of Louisiana School of Medicine.
Union University (Albany Medical College).
Vanderbilt University Medical Department.
University of Buffalo Department of Medicine.

Two years of college work

University of Alabama School of Medicine.
Boston University School of Medicine.
Bowdoin Medical School.
University of California Medical School.
Medical Department of the University of Southern California.
University of Cincinnati College of Medicine.
University of Colorado School of Medicine.
Columbia University College of Physicians and Surgeons.
Dartmouth Medical School.
Georgetown University School of Medicine.
Hahnemann Medical College and Hospital of Chicago.
University of Illinois College of Medicine.
Indiana University School of Medicine.
State University of Iowa College of Medicine.
State University of Iowa College of Homeopathic Medicine.
University of Kansas School of Medicine.
Jefferson Medical College of Philadelphia.
Marquette University School of Medicine.

University of Michigan Medical School.
University of Michigan Homeopathic Medical School.
University of Minnesota Medical School, and Medical Department Hamline University.
University of Nebraska College of Medicine.
Northwestern University Medical School.
University of Oklahoma School of Medicine.
University of Pittsburgh School of Medicine.
University of Pennsylvania School of Medicine.
Rush Medical College.
Syracuse University College of Medicine.
Medical College of the State of South Carolina.
University of Texas Department of Medicine.
University of Virginia Department of Medicine.
Medical College of Virginia.
Yale University School of Medicine.
Washington University Medical School.

Three years of college work

Cornell University Medical College.
Leland Stanford Junior University School of Medicine.
Western Reserve University School of Medicine.

More than three years of college work

Johns Hopkins University Medical Department.
Medical School of Harvard University.

Unclassified

College of Physicians and Surgeons, Boston.
Jenner Medical College.
Eclectic Medical University, Kansas City.
Lincoln Medical College.
Minneapolis College of Physicians and Surgeons.
Ohio State University College of Medicine and Ohio Medical University.
Medico-Chirurgical College of Philadelphia.
College of Physicians and Surgeons of San Francisco.
Tufts College Medical School.
University of Vermont College of Medicine.

Extinct

As listed on pages 514, 515.

Distributions of median alpha scores of these groups of schools with different entrance requirements are shown in table 37. The decided differences between the medians show that the entrance requirement is an important factor in determining the intelligence of the students graduated. The higher the requirements the more intelligent the group. The difference between the lowest group and the highest (medians 118.7 and 154.2) is as great as that between the geographical section showing the lowest intelligence and that showing the highest. No other classification exhibits as great differences in alpha scores as this.

TABLE 37

Distribution of alpha scores of graduates from schools with different entrance requirements

Alpha score	One year college	Two years college	Three years college	Further requirements	Extinct	Unclassified	Total
200–204	...	2	..	1	..	..	3
190–199	3	14	1	3	1	..	22
180–189	13	40	5	12	2	5	77
170–179	20	78	6	15	4	8	131
160–169	48	102	6	16	13	10	195
150–159	70	133	6	14	13	14	250
140–149	63	144	3	16	20	20	266
130–139	87	133	8	15	21	25	289
120–129	97	126	5	6	19	23	276
110–119	115	111	5	9	22	22	284
100–109	96	91	4	5	16	14	226
90– 99	76	71	..	..	13	12	172
80– 89	47	42	..	..	16	16	121
70– 79	44	20	..	..	8	4	76
60– 69	23	18	..	..	8	4	53
50– 59	18	11	1	..	4	3	37
40– 49	11	5	1	..	2	..	19
30– 39	7	...	..	..	..	..	7
20– 29	...	1	..	..	1	..	2
15– 19	1	...	..	..	..	..	1
Total......	839	1142	51	112	183	180	2507
Median....	118.7	135.9	146.3	154.2	120.5	126.4	129.2

The earnings of graduates from schools in these groups (table 38) show the same tendency to increase with the increase of entrance requirements, except that the highest group, including the Johns Hopkins Medical School and Harvard Medical School, report on the whole lower earnings than the preceding group. The differences given are striking and show clearly that the graduates from medical schools with high entrance requirements earn more than the graduates of other schools. This may be because the schools which have the more advanced educational basis on which to build lead their students to greater specialization, and that as specialists they have a higher earning capacity. That difference in length of previous experience is not mainly responsible for these differences in earnings is indicated by the medians for experience at the bottom of the table.

TABLE 38

Distribution of earnings of graduates from schools with different entrance requirements

Annual salary	One year college	Two years college	More than two years college	Extinct	Unclassified	Total
$30,000	3	9	..	..	..	12
18,000	2	11	2	1	..	16
16,000	5	18	2	1	1	27
12,000	9	20	1	4	2	36
10,000	18	41	8	4	4	75
8,000	29	44	7	7	7	94
6,000	59	95	20	13	10	201
4,000	120	173	18	29	31	371
3,000	110	123	17	25	21	297
2,500	50	39	4	12	14	119
2,000	74	54	6	13	8	155
1,500	29	26	2	6	3	66
1,000	18	19	6	1	5	49
500–999	9	8	1	..	..	18
Salary not known	304	462	69	64	72	971
Total......	839	1142	163	183	180	2507
Median...	$3795	$4807	$5300	$4107	$4150	...
Median score....	118.7	135.9	150.9	120.5	126.4	129.2
Median years' experience...	10.47	11.50	9.39	13.48	9.53	11.07

Classification According to Rating of American Medical Association

The general excellence of the school or the extent to which it attained the standard of the American Medical Association, as indicated by the rating given by the Association, served as a basis for the following classification. The American Medical Directory of 1918 was used as source of information.

Grouping of Schools by Rating of American Medical Association

Class A

University of Alabama School of Medicine.
Baylor University College of Medicine.
University and Bellevue Hospital Medical College.
Boston University School of Medicine.

Bowdoin Medical School.
University of Buffalo Department of Medicine.
University of California Medical School, and Hahnemann Medical College of the Pacific.
University of Cincinnati College of Medicine.
University of Colorado School of Medicine.
Columbia University College of Physicians and Surgeons.
Cornell University Medical College.
Dartmouth Medical School.
Detroit College of Medicine and Surgery.
Emory University School of Medicine.
Fordham University School of Medicine.
Georgetown University School of Medicine.
George Washington University Medical School.
University of Georgia Medical Department.
Hahnemann Medical College and Hospital of Philadelphia.
Medical Department Hamline University.
Medical School of Harvard University.
University of Illinois College of Medicine.
Indiana University School of Medicine.
State University of Iowa College of Medicine.
State University of Iowa College of Homeopathic Medicine.
Jefferson Medical College of Philadelphia.
John A. Creighton Medical College.
Johns Hopkins University Medical Department.
University of Kansas School of Medicine, and Kansas Medical College.
Leland Stanford Junior University School of Medicine.
Long Island College Hospital.
University of Louisville Medical Department.
Marquette University School of Medicine.
University of Maryland School of Medicine and the College of Physicians and Surgeons.
University of Michigan Medical School.
University of Michigan Homeopathic Medical School.
University of Minnesota Medical School.
University of Nebraska College of Medicine.
Northwestern University Medical School.
Ohio State University College of Medicine.
Minneapolis College of Physicians and Surgeons.
University of Oregon Medical School, and Willamette University Medical Department.
University of Pennsylvania School of Medicine.
University of Pittsburgh School of Medicine.
Rush Medical College.
Medical College of the State of South Carolina.
St. Louis University School of Medicine.
Syracuse University College of Medicine.
Medico-Chirurgical College of Philadelphia.
University of Tennessee College of Medicine.
University of Texas Department of Medicine.
Tufts College Medical School.
Tulane University of Louisiana School of Medicine.

Albany Medical College.
Vanderbilt University Medical Department.
University of Vermont College of Medicine.
University of Virginia Department of Medicine.
Medical College of Virginia.
Washington University Medical School.
Western Reserve University School of Medicine.
Yale University School of Medicine.

Class B

Chicago College of Medicine and Surgery.
University of Arkansas Medical Department.
University of Southern California Medical Department, and University of Southern California College of Medicine.
Eclectic Medical College, Cincinnati.
Hahnemann Medical College and Hospital of Chicago.
Chicago Homeopathic Medical College.
Chicago College of Medicine and Surgery, School of Medicine of Loyola University.
New York Homeopathic Medical College and Flower Hospital.
University of Oklahoma School of Medicine.
Temple University Department of Medicine.
Medical Department of the Texas Christian University.

Class C

College of Physicians and Surgeons, Boston.
Jenner Medical College.
Eclectic Medical University, Kansas City.
Lincoln Medical College.
College of Physicians and Surgeons of San Francisco.

Extinct

As listed on pages 514, 515.

Table 39 shows the results with respect to scores on intelligence examination alpha. Here again there are obvious differences between the intelligence levels of the groups. The difference between the median alpha scores of the groups from schools rated C and from those rated A is little more than half as great as between schools requiring one year of college work and those requiring college graduation for entrance, but it is, nevertheless, significant. It is interesting that the schools rated C stand as a group even below those schools in each list which have already become extinct. The extinct group is well below the whole group in intelligence, and also in earnings, although naturally the median experience is greater.

The earnings of graduates from schools rated B and C are reported as somewhat lower (table 40) than earnings of those from schools rated A and the differences in experience shown at the foot of table 40 are not such as entirely to account for this. It should

TABLE 39

Distribution of alpha scores of graduates from schools differently rated by the American Medical Association

Alpha score	A. M. A. rating			Extinct	Total
	Class A	Class B	Class C		
200–204	3	..	..	..	3
190–199	20	1	..	1	22
180–189	69	5	1	2	77
170–179	124	3	..	4	131
160–169	171	10	1	13	195
150–159	221	16	.	13	250
140–149	234	11	1	20	266
130–139	249	17	2	21	289
120–129	233	22	2	19	276
110–119	238	20	4	22	284
100–109	199	8	3	16	226
90–99	133	24	2	13	172
80–89	99	4	2	16	121
70–79	60	8	..	8	76
60–69	43	2	..	8	53
50–59	33	..	..	4	37
40–49	16	1	..	2	19
30–39	6	1	..	..	7
20–29	...	1	..	1	2
10–19	1	..	..	..	1
Total......	2152	154	18	183	2507
Median....	130.6	123.3	113.3	120.5	129.2

be noted, however, that the experience of medical officers from schools in group B is less than that of those from schools in the other groups.

Classification by Medical Sect

Comparisons between schools belonging to different medical sects were started by means of information given in the American Medical Directory for 1918. The institutions calling themselves "regular," "homeopathic" and "eclectic" were as follows:

Grouping of Schools by Medical Sect

Regular

University of Alabama School of Medicine.
University of Arkansas Medical Department.
Baltimore University School of Medicine.
Baylor University College of Medicine.
University and Bellevue Hospital Medical College.

College of Physicians and Surgeons, Boston.
Bowdoin Medical School.
University of Buffalo Department of Medicine.
University of California Medical School.
University of Southern California College of Medicine.
Chattanooga Medical College.
Cincinnati College of Medicine and Surgery.
University of Cincinnati College of Medicine.
University of Colorado School of Medicine.
Columbia University College of Physicians and Surgeons.
Cornell University Medical College.
Dartmouth Medical School.

TABLE 40

Distribution of earnings of graduates from schools differently rated by the American Medical Association

Earnings	A. M. A. rating			Extinct	Total
	Class A	Class B	Class C		
$30,000 and over	8	..	..	..	8
25,000	4	..	..	..	4
20,000	8	..	..	1	9
18,000	7	..	..	..	7
16,000	4	..	..	1	5
14,000	21	1	..	..	22
12,000	31	1	..	4	36
10,000	68	3	..	4	75
9,000	27	1	..	2	30
8,000	56	2	1	5	64
7,000	56	1	..	2	59
6,000	116	11	2	13	142
5,000	149	6	..	15	170
4,000	175	10	2	14	201
3,000	238	29	4	26	297
2,500	100	5	2	12	119
2,000	131	11	..	13	155
1,500	55	5	..	6	66
1,000	44	3	1	1	49
500–999	17	1	..	..	18
Earnings not known........	847	64	6	64	971
Total...........	2152	154	18	183	2507
Median.........	$4385	$3690	$3750	$4107	$4318
Median score....	130.6	123.3	113.3	120.5	129.2
Median years' experience.....	11.06	7.39	10.71	13.48	11.07

Dearborn Medical College.
Detroit College of Medicine and Surgery.
Emory University School of Medicine.
Ensworth Medical College.
Fordham University School of Medicine.
Georgetown University School of Medicine.
George Washington University Medical School.
University of Georgia Medical Department.
Grand Rapids Medical College.
Medical Department Hamline University.
Medical School of Harvard University.
University of Illinois College of Medicine.
Indiana University School of Medicine, and Physio-Medical College of Indiana.
State University of Iowa College of Medicine.
Jefferson Medical College of Philadelphia.
Jenner Medical College.
John A. Creighton Medical College.
Johns Hopkins University Medical Department.
University of Kansas School of Medicine, and Kansas Medical College.
University Medical College of Kansas City.
Leland Stanford Junior University School of Medicine.
Long Island College Hospital.
University of Louisville Medical Department.
Marquette University School of Medicine.
University of Maryland School of Medicine, and the College of Physicians and Surgeons.
Milwaukee Medical College.
University of Michigan Medical School.
University of Minnesota Medical School.
Mississippi Medical College.
University of Nashville Medical Department.
Maryland Medical College.
National University of Arts and Sciences Medical Department.
University of Nebraska College of Medicine.
Northwestern University Medical School.
Ohio State University College of Medicine.
University of Oklahoma School of Medicine.
University of Oregon Medical School, and Willamette University Medical Department.
University of Pennsylvania School of Medicine.
Medico-Chirurgical College of Philadelphia.
University of Pittsburgh School of Medicine.
Rush Medical College.
Saginaw Valley Medical College.
College of Physicians and Surgeons of San Francisco.
Sioux City College of Medicine.
Medical College of the State of South Carolina.
University of the South Medical College.
Southern Methodist University Medical Department.
St. Louis University School of Medicine.
Temple University Department of Medicine.
University of Tennessee College of Medicine.

Medical Department of the Texas Christian University.
University of Texas Department of Medicine.
Toledo Medical College.
Tufts College Medical School.
Tulane University of Louisiana School of Medicine.
Albany Medical College.
Vanderbilt University Medical Department.
University of Vermont College of Medicine.
University of Virginia Department of Medicine.
Washington University Medical School.
Western Reserve University School of Medicine.
Wisconsin College of Physicians and Surgeons.
Yale University School of Medicine.

Homeopathic

Atlantic Medical College.
Boston University School of Medicine.
Hahnemann Medical College of the Pacific.
Cleveland Homeopathic Medical College.
Detroit Homeopathic Medical College.
Hahnemann Medical College and Hospital of Chicago.
Chicago Homeopathic Medical College.
Hahnemann Medical College and Hospital of Philadelphia.
Hering Medical College.
State University of Iowa College of Homeopathic Medicine.
University of Michigan Homeopathic Medical School.
University of Minnesota College of Homeopathic Medicine and Surgery.
Missouri Medical College.
National Medical University.
New York Homeopathic Medical College and Flower Hospital.
Kansas City Hahnemann Medical College.
Southwestern Homeopathic Medical College and Hospital.

Eclectic

Hospital Medical College, Eclectic, Atlanta.
California Eclectic Medical College.
Chicago College of Medicine and Surgery.
Eclectic Medical College, Cincinnati.
Georgia College of Eclectic Medicine and Surgery.
Indiana Eclectic Medical College.
Eclectic Medical University, Kansas City.
Lincoln Medical College, Eclectic.
Chicago College of Medicine and Surgery, School of Medicine of Loyola University.
Eclectic Medical College of the City of New York.
Syracuse University College of Medicine.

Graduates from homeopathic medical schools made scores on examination alpha as much greater than those made by graduates from schools calling themselves eclectic as are the scores of Class A schools above those of Class C (table 41). The median alpha scores of graduates from "regular" schools fall approximately half way between those of groups from homeopathic and eclectic

schools. It is of course possible that homeopathic physicians were scrutinized with special care before they were commissioned in the army so that they were thus more carefully selected than the "regulars." The homeopathic group shows the same superiority in the matter of earnings, though this may be partly accounted for by its greater experience. The eclectic group reports lower earnings than the regulars, but this may be accounted for by its relative lack of experience (table 42).

TABLE 41

Distribution of alpha scores of graduates from schools of different medical sects

Alpha score	Regular	Homeopathic	Eclectic	Total
200–204	3	..	..	3
190–199	19	2	1	22
180–189	71	4	2	77
170–179	126	5	..	131
160–169	180	11	4	195
150–159	223	19	8	250
140–149	243	17	6	266
130–139	265	12	12	289
120–129	244	13	19	276
110–119	257	10	17	284
100–109	214	5	7	226
90– 99	148	8	16	172
80– 89	115	2	4	121
70– 79	68	..	8	76
60– 69	47	3	3	53
50– 59	37	..	..	37
40– 49	17	1	1	19
30– 39	6	..	1	7
20– 29	2	..	..	2
15– 19	1	..	..	1
Total.........	2286	112	109	2507
Median......	128.5	140.8	117.8	129.2

Comparison of Schools

Eight schools are represented by more than 75 graduates each. These groups are considered large enough to yield fairly reliable statistical information. Ten additional schools are represented by from 35 to 60 graduates. The information for these schools, although less reliable, is worthy of presentation. Table 43 gives, for each of these 18 schools, the number of graduates by which

TABLE 42

Distribution of earnings of graduates from schools of different medical sects

Earnings	Regular	Homeopathic	Eclectic	Total
$30,000 and over	8	..	..	8
25,000	4	..	..	4
20,000	9	..	..	9
18,000	7	..	..	7
16,000	5	..	..	5
14,000	20	1	1	22
12,000	32	3	1	36
10,000	69	5	1	75
9,000	28	1	1	30
8,000	60	2	2	64
7,000	54	4	1	59
6,000	123	12	7	142
5,000	158	7	5	170
4,000	187	6	8	201
3,000	258	20	19	297
2,500	109	6	4	119
2,000	144	5	6	155
1,500	62	2	2	66
1,000	43	1	5	49
500–999	17	..	1	18
Earnings not known	889	37	45	971
Total	2286	112	109	2507
Median	$4350	$4583	$3750	$4318
Median score	128.5	140.8	117.8	129.2
Median yrs. experience	10.11	13.79	7	11.07

a school was represented, median alpha score, pre-medical education, total education, experience, annual earnings, percentage of the graduates who were members of the American Medical Association, percentage known to have been promoted while in the army and information concerning the specialties of graduates.

It is not surprising to find that a few schools are seemingly of outstanding excellence. There are, for example, among these 18 medical schools 5 which rank exceptionally high in intelligence of graduates. These 5 constitute two groups, the first of which comprises the Johns Hopkins Medical School and the Medical School of Harvard University, and the second, somewhat lower in intelligence of graduates, the College of Physicians and Surgeons

TABLE 43

Comparison of schools

Graduates from:	Number students 1917	Entrance requirements 1917	Number cases	Median alpha score	Median pre-medical education	Median total educ.	Median experience	Median earnings	Percentage A. M. A. members	Percentage promoted in army	Percentage general practice	Percentage eye, ear, nose and throat	Percentage internal medicine	Percentage surgery
Columbia University College of Physicians and Surgeons	491	2 yrs. Col.	79	148.8	15.13	18.42	12.03	$5500	43.8	21.3	17.0	8.6	14.3	38.6
Medical School of Harvard University	357	Graduation[1]	77	153.1	15.32	18.86	11.25	5000	41.6	19.5	16.9	12.7	11.3	29.6
University of Illinois College of Medicine	213	2 yrs. Col.	88	129.4	11.83	15.83	9.1	4750	50.0	18.2	34.7	10.7	5.3	37.7
Jefferson Medical College of Philadelphia	540	2 yrs. Col.	81	129.2	12.59	16.5	9.83	4722	46.9	33.3	28.1	17.2	10.9	32.8
University of Maryland School of Medicine and the College of Physicians and Surgeons	298	1 yr. Col.[2]	102	116.7	11.83	15.73	12.05	4944	38.2	24.5	35.6	21.1	7.8	18.9
Northwestern University Medical School	247	2 yrs. Col.	92	139.3	13.24	17.08	9.07	5889	53.3	19.6	25.3	13.3	3.6	49.4
University of Pennsylvania School of Medicine	585	2 yrs. Col.	81	148.8	13.8	18.09	12.67	5300	54.3	33.3	20.0	13.8	9.2	26.2
Rush Medical College	567	2 yrs. Col.	118	148.8	15.09	17.58	12.21	5500	50.8	25.4	26.1	8.7	14.1	37.0
ALL COLLEGES	...	....	2507	129.2	12.16	16.07	11.07	4318	50.7	22.3	33.3	9.0	8.0	30.0
University and Bellevue Hospital Medical College	429	1 yr. Col.[2]	54	126.7	11.88	15.86	15.5	5000	29.6	20.4	20.4	4.1	14.3	40.8
University of Buffalo Department of Medicine	196	1 yr. Col.[2]	39	122.5	11.76	15.63	8.88	3000	38.5	7.7	20.6	17.6	8.8	26.5
Johns Hopkins University Medical Department	359	Graduation	35	155.8	15.56	19.44	7.67	5250	42.9	37.1	22.2	18.5	25.9	11.1
University of Louisville Medical Department	118	1 yr. Col.[2]	60	113.[illegible]	11.70	15.68	8.5	3250	40.0	21.7	45.2	5.8	0	26.9
Chicago College of Medicine and Surgery, School of Medicine of Loyola University	643	1 yr. Col.	60	117.0	11.69	15.68	4.14	3318	16.0	....	30.2	3.8	3.8	26.4
University of Michigan Medical School	322	2 yrs. Col.	47	136.3	13.17	16.86	12.69	4833	48.9	25.5	31.0	16.7	7.1	31.0
St. Louis University School of Medicine	254	1 yr. Col.[2]	50	122.5	11.96	15.94	11.36	5000	52.0	24.0	31.1	22.2	6.7	25.7
University of Tennessee College of Medicine	122	1 yr. Col.	62	93.3	12.15	15.96	11.23	3250	30.6	14.5	54.7	9.4	3.8	22.6
Tulane University of Louisiana School of Medicine	267	1 yr. Col.	51	117.5	12.0	16.67	9.00	3875	37.3	21.6	33.3	15.5	2.2	35.6
Vanderbilt University Medical Department	152	1 yr. Col.	41	124.6	12.8	16.5	6.04	3667	46.3	31.7	34.5	6.9	13.8	37.9

[1] Harvard requires a bachelor's degree, *or* standing in upper third of class during two or three college years.
[2] 2 yrs. college beginning 1918.

of Columbia University, the School of Medicine of the University of Pennsylvania and Rush Medical College.

The graduates of the medical schools of Johns Hopkins University and Harvard University present the highest scores on examination alpha and few exceptionally low scores, 100 points being practically the minimum. They also spend relatively more time on their medical training and command large earnings. In the latter respect, however, they are surpassed by the graduates of Northwestern University Medical School, the College of Physicians and Surgeons of Columbia University and Rush Medical College.

The earnings reported by the group from Northwestern University Medical School are notably high. This is not due to greater experience, for the median (9 years) for the group is two years less than that for the entire group of medical officers. It is not to be explained geographically, for in general schools in the same section show smaller earnings. Probably the unusually large proportion of surgeons is largely responsible for the high rank of the school in earnings of its graduates. It is interesting to compare the three Chicago schools from which there is a considerable number of cases: The University of Illinois College of Medicine, Northwestern University Medical School and Rush Medical College. The alpha medians are 129.4, 139.3, and 148.8, respectively. The median number of years devoted to education is 15.8, 17, 17.6, respectively; the median experience is 9.1, 9.1 and 12.2 years, and the median earnings, $4750, $5889 and $5500.

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